

Report of the California Water Meter Survey

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California Water Meter Test Survey

Executive Summary

History and Background

A cooperative project among four water meter manufacturers (the Water Meter Manufacturers Group, WMMG), the California Division of Measurement Standards (DMS), and California county weights and measures laboratories was undertaken to assess meter accuracy performance and test lab practices/procedures for 5/8" x 3/4" utility-type water meters. The intended application for these meters is submetering. Three water meter manufacturers, Badger Meter, Neptune Technology Group and Master Meter funded the project. Four manufacturers, Badger Meter, Master Meter, Neptune Technology Group and Sensus Metering Systems each provided 10 positive displacement water meters from their companies for this project. Five meters from each manufacturer had registers that indicated in gallons and five indicated in cubic feet. The California Division of Measurement Standards provided a project coordinator, two staff members to transport and witness tests at county laboratories, plus staff time and support to test the water meters. The California counties that participated in the survey provided staff time and the use of their facilities to conduct tests on the water meters.

The objectives of the survey were to:

- Assess how well test results agreed from laboratory to laboratory;
- Compare the amount of variation in repeat results for the laboratories;
- Determine if and which laboratories showed offsets in test results from the DMS results;
- If possible, identify possible causes for offsets in test results and any atypical repeatability results for some laboratories;
- Assess the significance of any offsets and variation in individual test results relative to the tolerances for the water meters;
- Compare the test results at the minimum flow rate for test drafts of 10 gal and 5 gal, and evaluate how the uncertainty associated with the readings of the indicator affected the test results;
- Assess whether or not, and to what extent, the different characteristics of test facilities affected the test results; and
- Identify possible corrective actions that may improve consistency among the laboratories.

Methodology

The basic test format for the survey was derived from NIST Handbook 44, Section 3.36 Water Meters Code. Three repeat tests were conducted at three flow rates: normal (15 gpm), intermediate (2 gpm) and the minimum flow rate (0.25 gpm). The three repeat tests are the minimum required to obtain a measure of the repeatability of the test results in each laboratory for each meter. The manufacturers and DMS conducted tests at some additional sizes of test drafts as shown in the table below. The test drafts run by the counties are also included.

Flow rate	Manufacturers		DMS		Counties	
Flow rate	gal Meters	ft ³ Meters	gal Meters	ft ³ Meters	gal Meters	ft ³ Meters
15 gpm	50 or 100 gal	5 ft ³ or 100 gal	5 ft ³	5 ft ³	50 or 100 gal	5 ft ³
2 gpm	40, 20, 10 gal	4, 2, 1 ft ³ or 100 gal	20, 10 gal	2, 1 ft ³	10 gal	1 ft ³
0.25 gpm	20, 10, 5 gal	2, 1, 0.5 ft ³ or 10 gal	10, 5 gal	1 ft ³ , 5 gal	10, 5 gal	1 ft ³

All laboratories recorded the indicated volume of the meter-under-test through a visual reading of the mechanical registration device, i.e., the indicating element. These registration devices provided “full-face” test indices, where one full revolution of the index sweep hand corresponds to either 1.0 cubic feet or 10 gallons. The smallest divisions of the registration devices were 0.1 gal and 0.01 ft³. Some of the registers had marks for one-half of the smallest division. One of the county test officials read the meters to the nearest graduated division. Several others read the registers to $\frac{1}{4}$ division and $\frac{1}{2}$ division. The remainder read the registers to 0.1 division.

DMS used a Ford test bench to test the meters, but used high-resolution volumetric provers and gravimetric tests as reference standards. Tests at 15 gpm used a 10-ft³ volume standard. Test drafts of 1 ft³ also used a volume standard as the reference. All of the other sizes of test drafts used the gravimetric method as the reference standard and included the air buoyancy correction. DMS corrected all deliveries for any differences from the nominal test values. Manufacturers 1, 2 and 3 performed their meter tests gravimetrically. Manufacturers 2 and 3 made the air buoyancy correction in their test process; manufacturer 1 did not. Manufacturer 4 performed the meter tests using volume standards, so the air buoyancy correction does not apply. The manufacturers corrected all deliveries for any differences from the nominal test values.

Each meter manufacturer tested its own meters at the beginning and the end of the survey. During normal testing of production meters, the manufacturers test their meters using electronic pulsers on the meters (i.e., without the meter registers) to determine the volume of water that passed through the meters. For the purpose of this survey, the manufacturers tested the meters with the registers on the meters and visually read the meters as is done in the California water meter laboratories. It was agreed that the DMS laboratory would be the reference laboratory for the survey. DMS also tested the meters at the beginning and the end of the survey (after the manufacturers’ tests at the beginning and before the manufacturers’ tests at the end of the survey).

The 40 meters from the four manufacturers were divided into eight groups of five meters. Each group had one meter from each manufacturer plus one additional meter from one of the manufacturers. The meters with registers indicating in gallons and those indicating in cubic feet were in separate groups, i.e., they were not mixed together in the same group.

The California counties that volunteered to participate in the survey chose to test either one group of meters or to test two groups of meters. The reason to have laboratories test two groups of meters was to collect more data for each county and to allow a modified form of Youden plot

analysis¹ to be performed on the test results. Although the water meter test plan differed significantly from the prescribed procedure for the Youden plot analysis, it allowed another approach to examine the potential biases in test results for the participating county laboratories. For the water meter survey, the differences in the average test results for the county lab from the average test results as determined by DMS for each meter were computed. Then the average differences for meters from the same manufacturers (to the extent possible) in the two groups of meters tested were plotted against each other for each flow rate at which the meters were tested. The median offset of the differences from the origins of the x- and y-axes is a measure of the bias that existed in the test results in the same way as described in the paper by W.J. Youden. Similarly, the randomness of the plots could also be examined. The details of the individual graphs are not explored in this report, but the graphs are included so that each laboratory may study their distribution of the differences from the DMS results.

The test results were analyzed and graphed in different ways to evaluate biases and repeatability characteristics for the different laboratories. It is recommended that all of the charts be reviewed to obtain a thorough understanding of the test results.

General Observations

1. There was a wide variation in the test facilities from county to county. Most laboratories have the Ford test bench and reference tanks. The number of meters that could be tested in each test bench varied significantly. A few counties could test only two water meters at a time. Some test benches had the capacity to test 12 to 16 meters at a time. Two laboratories did not have test benches and connected meters together using pipe connectors and segments of hose.
2. Several counties had test systems that utilized pumps and water was recirculated in the tests. In several cases, the pumps tended to heat the water throughout the day, due to the large number of tests conducted and the slow flow rates for some of the tests.
3. There are several potential sources of error when testing water meters. These include reading and recording errors when recording the start and stop readings for the meters for each test draft, parallax and eccentricity errors associated with the meter registers, the failure to stop water deliveries exactly on the reference graduations of the reference tanks, the inability to correct for the amounts of water different from the nominal volume when the water level is not exactly on the reference graduations, round-off errors when reading and recording the start and end readings of each meter test, and the granularity of different variables, which can be significant when the effects of several variables combine.

¹ The Youden plot analysis is described in the paper, "The Sample, The Procedure, and The Laboratory," by W. J. Youden, National Bureau of Standards, as published in **Report of Analytical Chemists**, 1960. Available at:

<http://www.nist.gov/pml/wmd/labmetrology/upload/samp-prod-lab-youden.pdf>

4. Reading errors occurred relatively frequently when recording the indications on the meter registers, but the frequency of reading errors varied from lab to lab. The registers on some of the meters contributed to some of the reading errors. A number of the reading errors might have been detected and corrected if each of the county officials had computed the meter errors for the tests conducted for this survey. Some counties have a policy to retest all meters that fail the initial test. If a meter passes the retest, the county will pass the meter. Under this policy, a retest of the meters generally will eliminate the reading error as a factor in the pass/fail decision for the meters, since it is unlikely that a second reading error would occur in a repeat test for the same meter.
5. The size of the test draft for the tests at the maximum flow rate of 15 gpm varied from laboratory to laboratory. Typically, test drafts of 50 and 100 gal were used to test meters indicating in gallons. Generally, test drafts of 5 and 10 ft³ were used to test meters indicating in cubic feet. The different sizes of the test drafts at the maximum flow rate did not appear to have a significant effect on the test results.
6. There is a significant variation in the results of individual meter tests. The variation in the percent meter error for individual test results increased as the flow rates and sizes of the test draft decreased; however, when the meter errors are expressed in volume units, the variation on the test results is relatively consistent across different sizes of test drafts at the same flow rate. The apparent increase in variation of the percent meter error in the smaller test drafts is due to the smaller volume of the test draft used in the denominator of the calculation of the percent meter errors. The test results in percent meter error at the minimum flow rate tended to have significantly more variation than results at the higher flow rates with the larger test drafts. However, because of the relatively large variability (i.e., large uncertainty) in the percent meter errors associated with small test drafts at the minimum flow rate, it is difficult to draw conclusions about biases.
7. The test results for a few laboratories varied significantly more than for most of the other laboratories.
8. In some cases, there are statistically significant (detectable) offsets from one lab to another. In most cases, these offsets are “small” relative to the applicable tolerance for the flow rate. At the minimum flow rate, some of these offsets are relatively large compared to the tolerance. The combination of a laboratory offset from DMS results combined with the variation in individual meter test results caused some significant variations in results from laboratory to laboratory.
9. The accuracy of several meters appears to have changed at the minimum flow rate during the test cycle. The majority of the meters was from one manufacturer. The fact that the accuracy of several meters changed quite significantly after a relatively small volume of water passed through the meters during the survey is a concern. It should be noted that the meters used in the survey experienced multiple start-up/air-purge cycles (between 7 and 13 such cycles), while in actual applications, meters experience only two such cycles (during a test by a county lab and then installation in the field). Experts in the design of the meters and the factors that may affect the performance

characteristics of the meter will have to assess how the multiple start-up/air-purge cycles affected the performance of the meters used in the survey.

10. Different volumes of water passed through the different groups of meters depending upon the number of labs that tested each group of meters. The maximum amount of water that passed through the meters with gallon registers was approximately 4000 gallons. The maximum amount of water that passed through the meters with cubic feet registers was approximately 600 ft³.

General Conclusions

1. Reading errors are a significant source of errors in the tests of meters. Reading errors occurred relatively frequently, but the frequency of reading errors varied from lab to lab. In the limited amount of witnessed testing, it seemed that test officials who were new to the process of testing meters made more reading errors than experienced test officials. However, even some, but not all, experienced test officials made some reading errors. The care with which people read the meters and double-checked the readings affected the number of reading errors that occurred.
2. The registers on some of the meters contributed to some of the reading errors. In particular, one brand of meter register made the change in the smallest displayed digit of the register with the transition beginning between 6 and 7 on the outer dial and completed the transition between 8 and 9 on the outer dial. If the test official was not aware of the point of transition in the dial readings, reading errors often occurred when the start or end readings were after the transition was completed, but before the dial indicator passed the zero graduation.
3. Laboratories using the reference tanks that are often part of the Ford test bench must take care to ensure that the water level in the tank is on the reference graduation. There appears to be a tendency to deliver more water into the reference tanks at the 15- and 2-gpm flow rates and still call the reference volume of water as equal to the nominal volume of the test. This practice tends to result in a bias of overregistration for the meter error.
4. The within-series standard deviations for the meters for individual laboratories underestimate the standard deviations of the parent normal distributions for the performance characteristics of the meters. More data are needed to obtain better estimates of the combined within-series and between-series standard deviations.
5. It appears that a range in percent meter error of up to 2.25% at 0.25 gpm for the 5-gal test draft can be expected simply based upon the repeatability of the meter and the test procedure. Laboratories that frequently have range values greater than 2.25% at 0.25 gpm for the 5-gal test draft should review their laboratory facility and test procedures to determine if anything in the laboratory or the test procedure is contributing to the large variability in the test results.

General Recommendations

1. Care must be taken to reduce and detect reading errors in the test process. Several actions can be taken to reduce and detect reading errors. First, the test official must take care to read the meter indications correctly. Next, the test official should double-check the readings. The percent meter errors should be calculated after each test run (or, at least before the meters are removed from the test bench) to determine if any unusual test results exist that might correspond to reading errors. This will allow repeat tests to be run to check if the unusual test result is due to the meter or a reading error. The table provided in the report that lists the magnitudes of reading errors on the percent meter error calculations should be used to help identify where potential reading errors may exist. Some laboratories have the policy to retest the meters that fail an individual test. This practice can be helpful to check if an out-of-tolerance meter error may be due to a reading error, since it is unlikely that the test official will make the same reading error on repeat tests of the meter. Finally, supervisors should frequently check the readings of test officials who are new to the water meter test process and the water levels in the reference tanks to ensure that the test officials are reading the meters correctly and stopping the deliveries on the reference graduation.
2. Meter manufacturers should check to ensure that the transition zone at which readings of the meter registers turn over to the next digit occur when the test index sweep hand crosses the zero mark on the test index. Similarly, manufacturers should check that the sweep hands move at a constant rate around the dial and always cross the graduations at the appropriate times as other dials or numbers are crossing the appropriate graduations or changing the indications.
3. It is recommended that corrections be made for the actual volume of water used in a meter test when the amount of delivered water is not on the nominal volume reference graduations. The Ford reference tanks routinely provided with the Ford test benches lack the resolution to make precise corrections for the deviations of the delivered volume of water from the nominal quantity. Volume standards with higher resolution necks or gravimetric test methods are recommended for use. Due to the cost of changing the reference standards in the test system, long-term planning should establish how best this change could be made.
4. Meter readings should be taken to 0.1 division of the dial for the test index sweep hand. Although reading errors have a relatively small impact on the overall variability of meter results, there are cases where rounding errors can go in opposite directions and have a large impact on individual test results. The effect of round-off errors can be effectively eliminated by recording meter readings to 0.1 division of the dial with the test index sweep hand without requiring any significant additional time in the test process.
5. County laboratories that have within-series standard deviations that are significantly larger than those reported by DMS and the manufacturers should review their facilities

and test procedures to determine if there is anything in the test facility or the test procedures that may be causing the significantly larger standard deviations.

6. Manufacturer 1 should investigate why its results at the 15-gpm flow rate are offset by about 0.5% from the results of DMS and the other manufacturers.
7. The manufacturer(s) that had meters change accuracy significantly at the minimum flow rate over the time period and volume of water measured during the survey should examine the possible causes of the changes and take steps to reduce the changes so that the meters will perform within tolerance over the time period and throughput for which the meters are intended to be used.
8. DMS and county laboratory 51 should examine why its test results at the 15-gpm flow rate are so different from DMS and the other laboratories.
9. County laboratories 34 and 93 should time the tests at the minimum flow rates to ensure that the tests are conducted at or above 0.25 gpm. It is recommended that all of the test laboratories routinely time the tests, especially at the minimum flow rate, to ensure that the tests are performed at the specified flow rates.
10. County laboratory 26 should modify its test system so that it eliminates the potential for air to pass through the meters during a test. The laboratory should change the test system such that the reference tanks can be drained and tests start at well-defined starting points.
11. The test results for County 43 had peculiar variations in its test results compared to other laboratories. The standard deviation at 0.25 gpm for the 10-gal test draft was larger than those of other labs. Upgrades of its test facility and reference standards are recommended.
12. DMS and county laboratories 34, 57 and 85 should examine the test facilities and test procedures used in these laboratories in an effort to identify possible causes for the rather large within-series standard deviations that occurred.

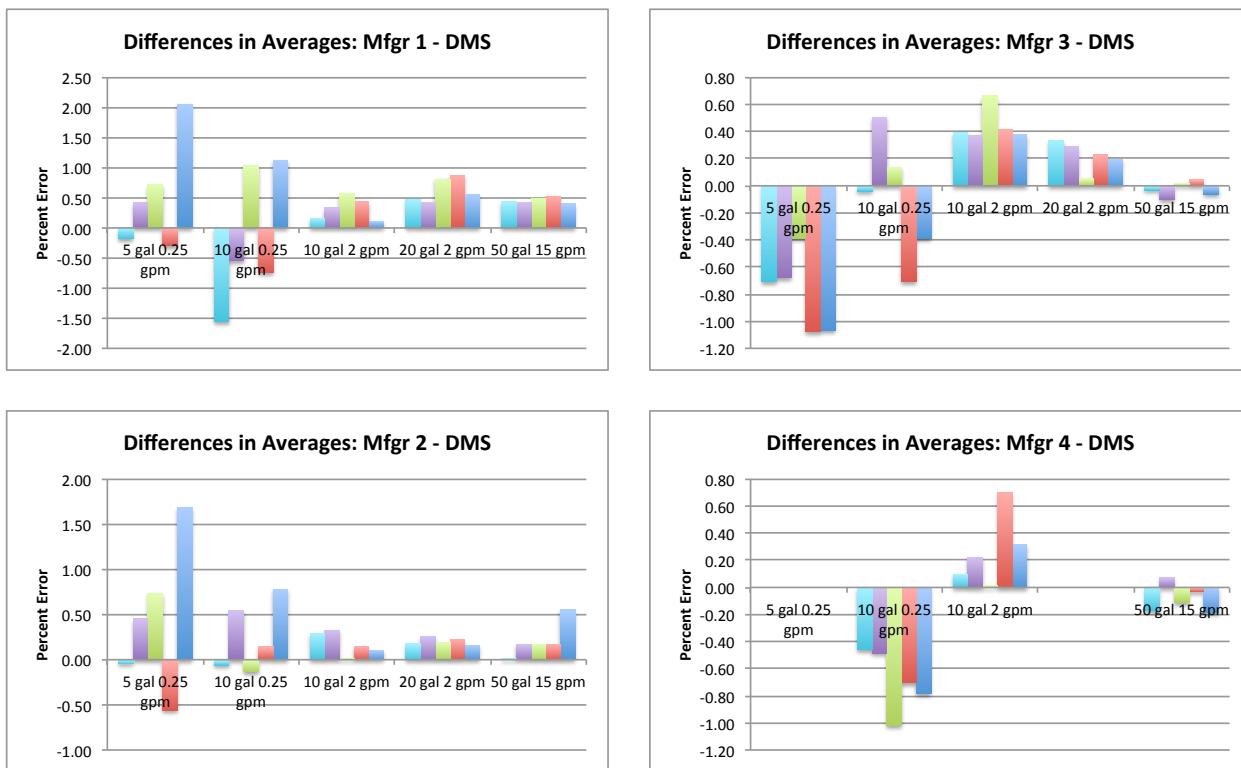
Presentation of the Test Results

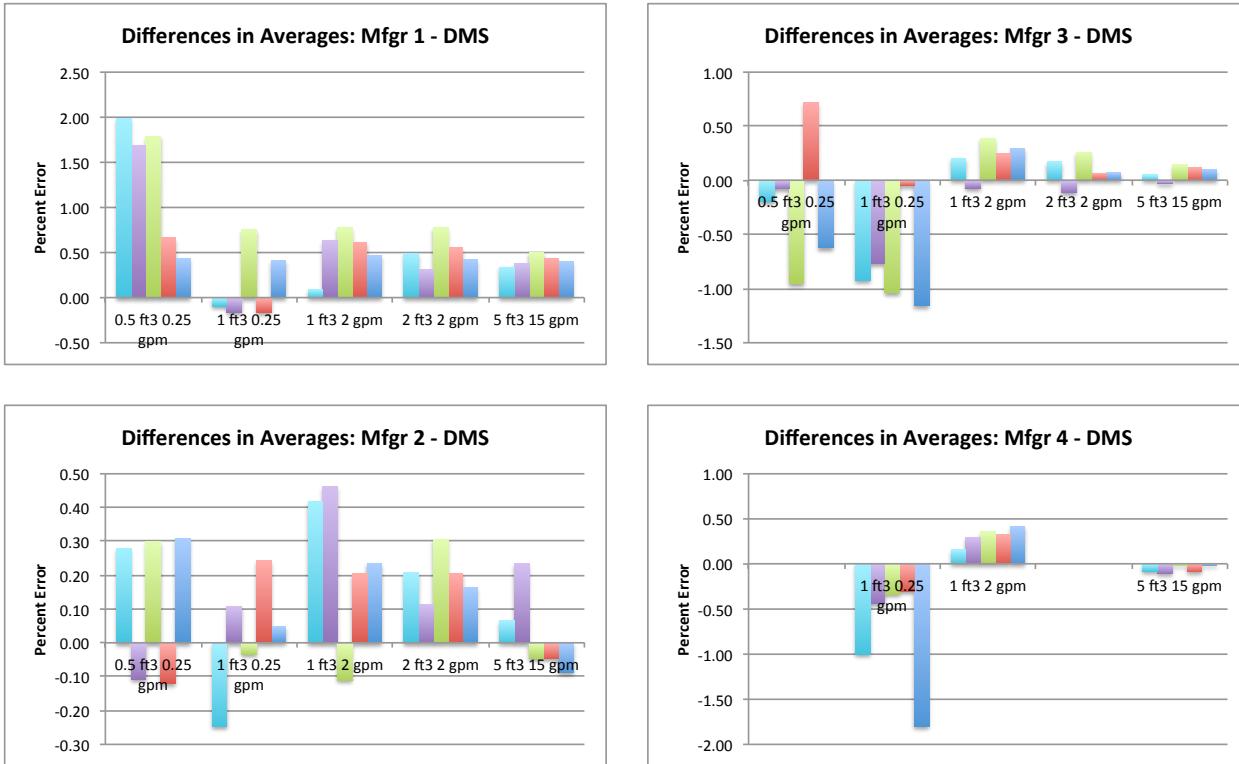
The test results are presented in several different ways, because no single approach can adequately represent the test results. Several questions that must be asked: "What are the causes of the observed results? How much of the biases are due to the meter, the test facility, the test equipment or the test procedure? Do the performance characteristics of meters change depending upon the flow characteristics of the installation?" A large amount of data has been collected, which is presented in this report. Judgments made in the analysis of the data can vary from one person to another, so virtually all of the data are included so that others can study the data, question the conclusions drawn from the data, and draw their own conclusions.

The order of presenting the test results is to first present the broader perspective and then progress to the more detailed analyses. First, a comparison of the test results for the manufacturers and DMS is provided as a foundation on which to assess the results for the county labs compared to DMS. This comparison gives an indication of how well one can expect test results to agree.

Manufacturer and DMS Test Results at Start of Survey

The DMS laboratory was specified as the reference laboratory against which the results of the county results would be compared. Nevertheless, it is interesting to compare the test results for the meter errors as determined by the manufacturers and DMS at the start of the water meter survey. The following charts show the differences in the average test results for the manufacturers from the DMS values for the meters. There are two sets of four charts. For each manufacturer, the **first set of charts** is for the meters with **gallon registers** and the **second set of charts** is for meters with **registers in cubic feet**.





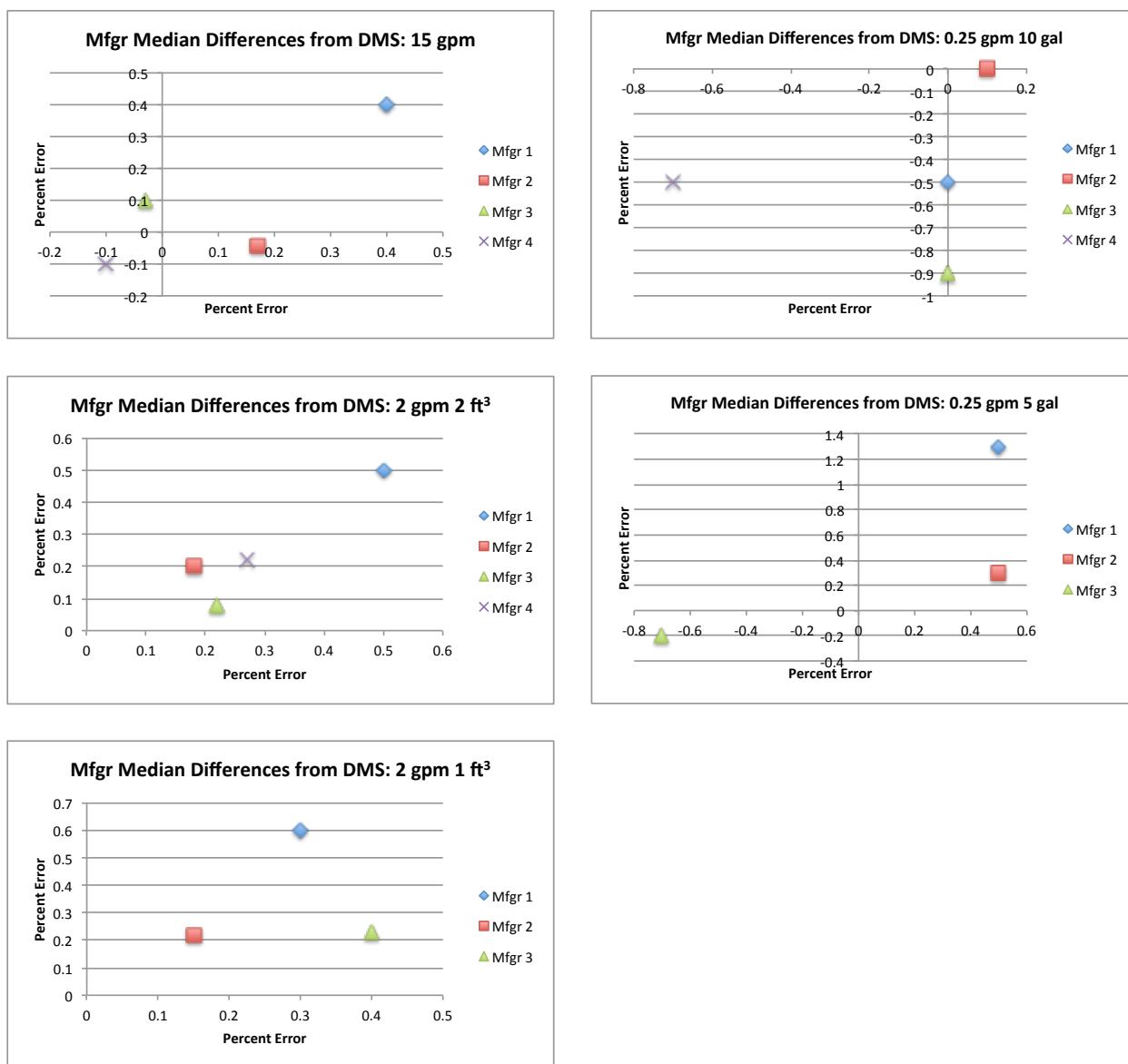
For the tests run at 15 gpm, which has the largest test draft, the test results for three of the four manufacturers agree with the DMS results quite well. The results for manufacturer 1 show an offset of approximately 0.5% in meter error at 15 gpm for both sets of meters. Most of the manufacturers tend to have more positive meter errors at 2 gpm than DMS determined. Two manufacturers measured more negative errors at 0.25 gpm than did DMS, while the results for the other two manufacturers were mixed.

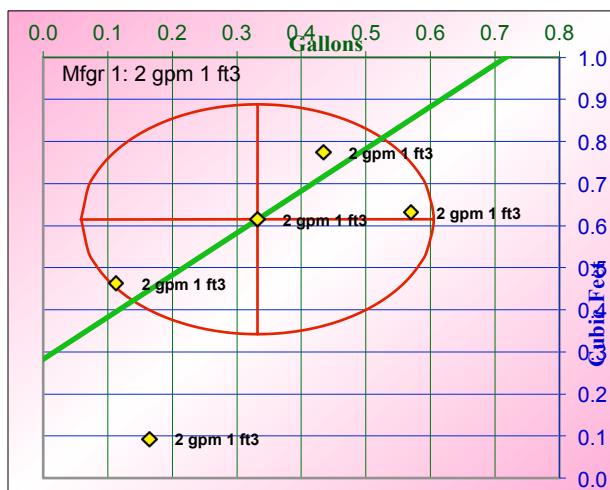
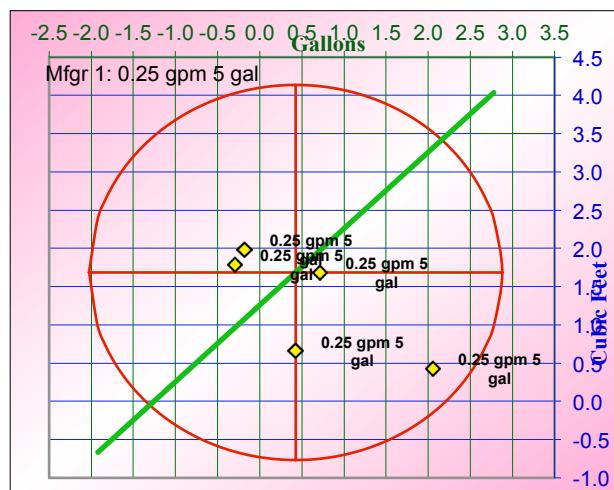
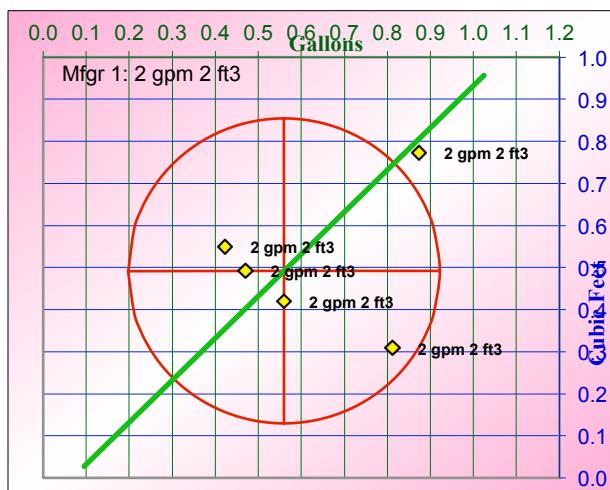
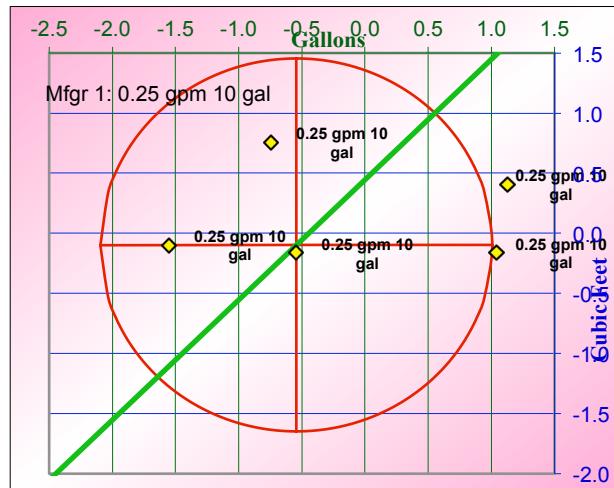
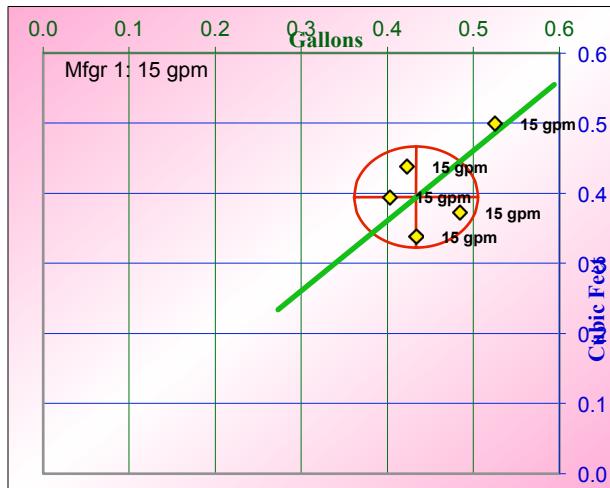
DMS used a Ford test bench to test the meters, but used high-resolution volumetric provers and gravimetric tests as reference standards. Tests at 15 gpm used a 10-ft³ volume standard. Test drafts of 1 ft³ also used a volume standard as the reference. All of the other sizes of test drafts used the gravimetric method as the reference standard and included the air buoyancy correction. DMS corrected all deliveries for any differences from the nominal test values. All tests conducted by the manufacturers were done gravimetrically. Manufacturers 1, 2 and 3 performed their meter tests gravimetrically. Manufacturers 2 and 3 made the air buoyancy correction in their test process; Manufacturer 1 did not. Manufacturer 4 performed the meter tests using volume standards, so the air buoyancy correction does not apply.

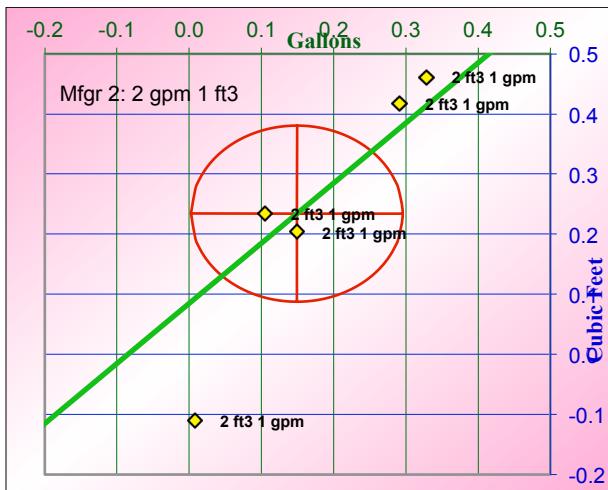
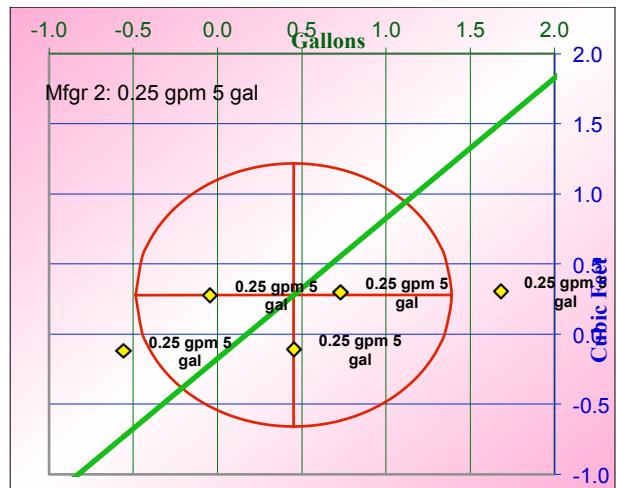
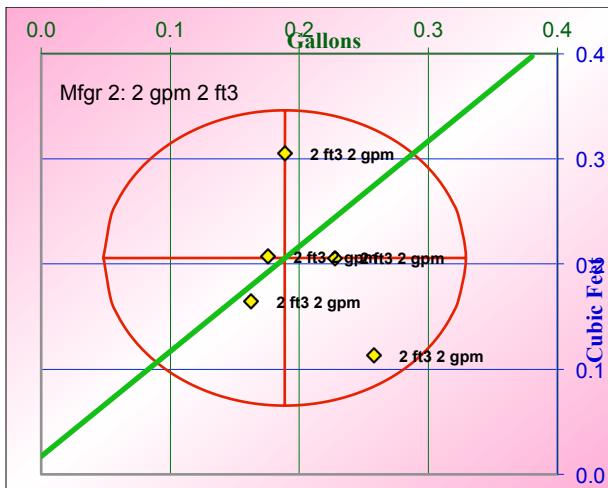
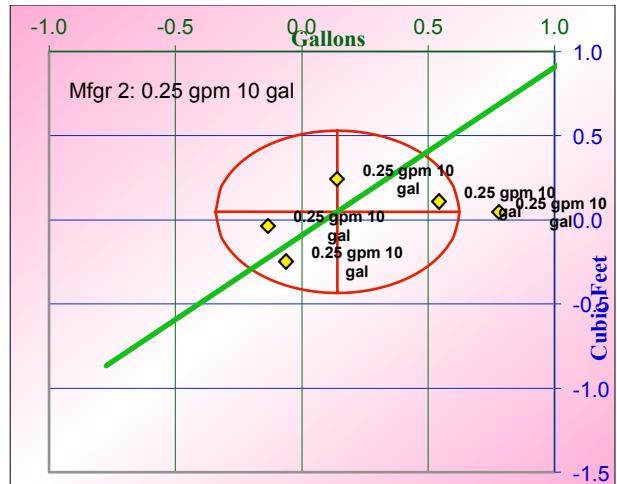
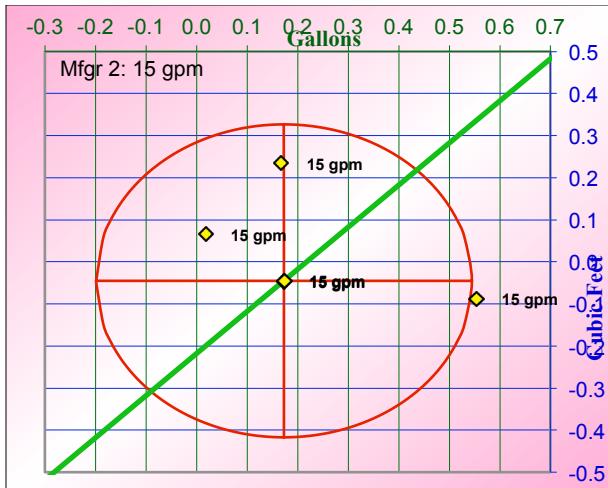
The differences in meter errors for the manufacturers' results compared to the DMS results can be graphed as a Youden plot by plotting the average error differences for the meters indicating in gallons versus the average error differences for the meters indicating in cubic feet. The Youden plot is simply another way to view the results portrayed in the charts above. Please note that the scales for the axes change from chart to chart. The important characteristics of the Youden plots are to observe the offset of the median values from the

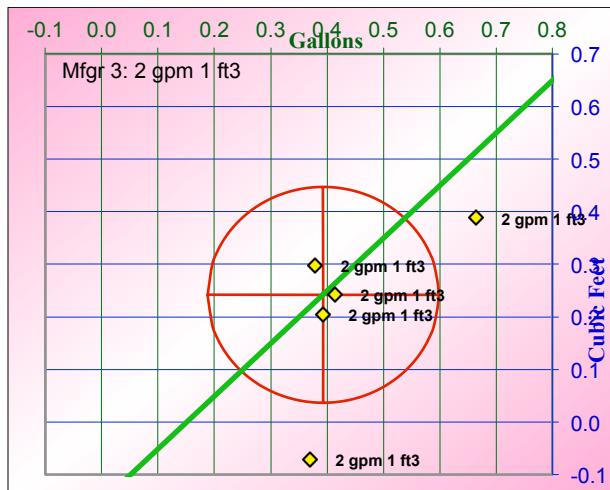
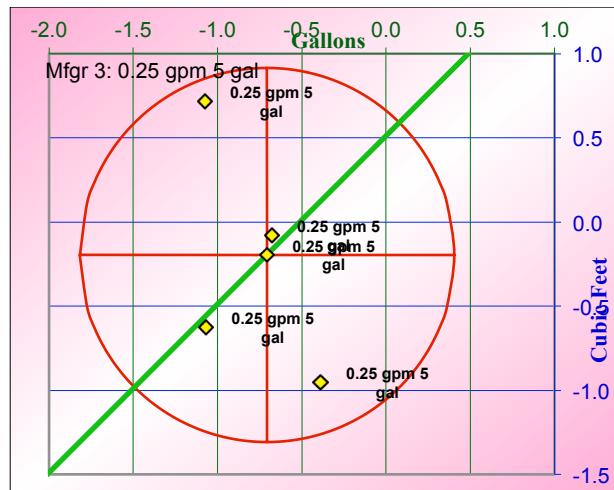
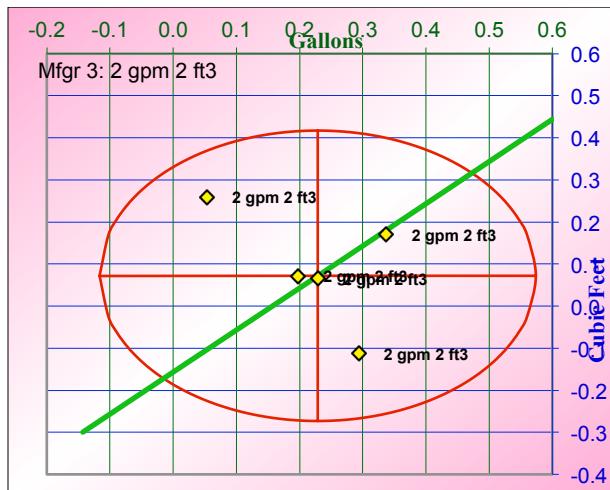
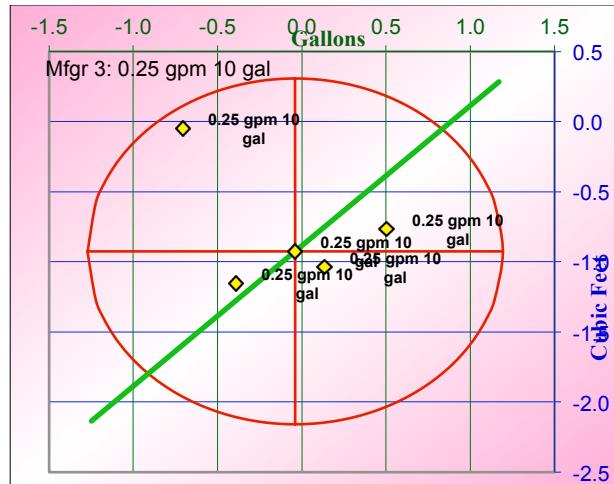
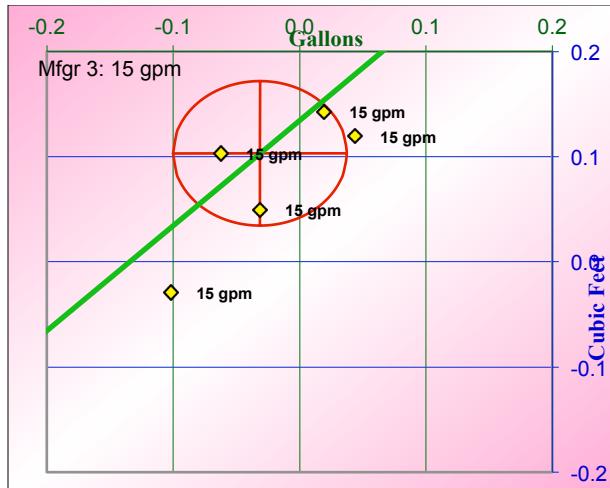
origins (0,0) of the axes and the amount of scatter in the points. If the median value for one axis is offset from the origin, but the other median value is not offset from the origin, it indicates that one set of meters had biases in the results, but the other did not. Points that lie along the 45-degree line in the upper right and lower left quadrants generally indicate systematic errors (biases) in the test results. If the results are scattered about in all quadrants away from the 45-degree line, these results indicate random errors. Based upon the variations observed in all of the test results, differences from the origin of 0.2% error to 0.3% error at 15 gpm are probably not significant.

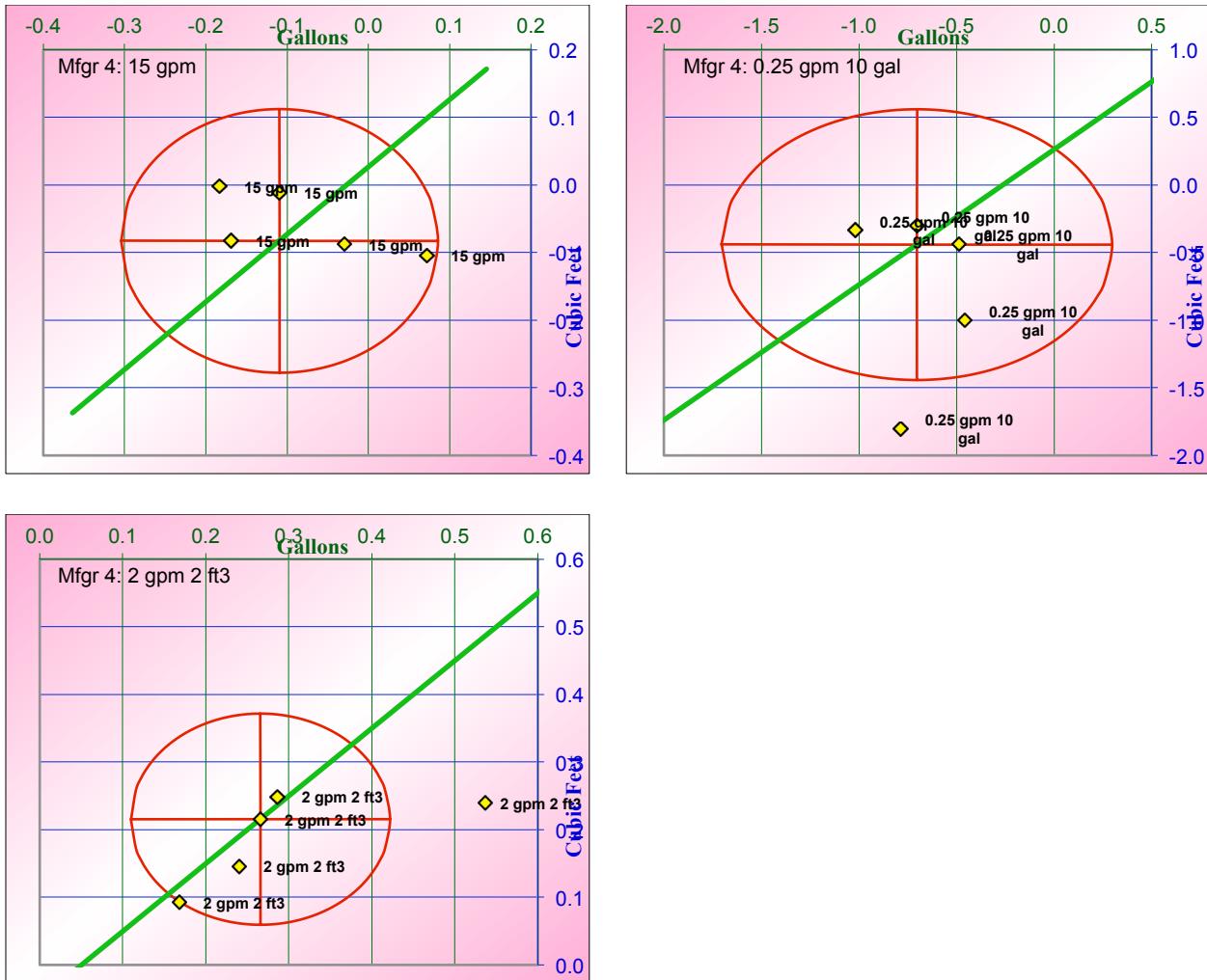
First, the median differences for each manufacturer from the DMS start values for each flow rate are provided, because these graphs more clearly indicate the general offsets of manufacturer's results from the DMS results.











The Youden plots show that manufacturer 1 tended to have significant offsets from the DMS values (except for 0.25 gpm for the 10-gal test draft). The offsets for manufacturer 1 are greater than for the other manufacturers. There was a significant offset for manufacturer 3 at 0.25 gpm for the 10-gal test draft, but the results for the other tests agreed quite well.

Manufacturer and DMS Test Results at End of Survey

The differences in the average test results obtained by the manufacturers from the average results obtained by DMS for tests conducted at the end of the survey are shown below and may be compared to the differences observed at the start of the survey. There are two sets of four charts. For each manufacturer, the **first chart** is for the meters with **gallon registers** and the **second chart** is for meters with **registers in cubic feet**. Be aware that Manufacturer 4 performed only one test at each flow rate for each size of test draft.





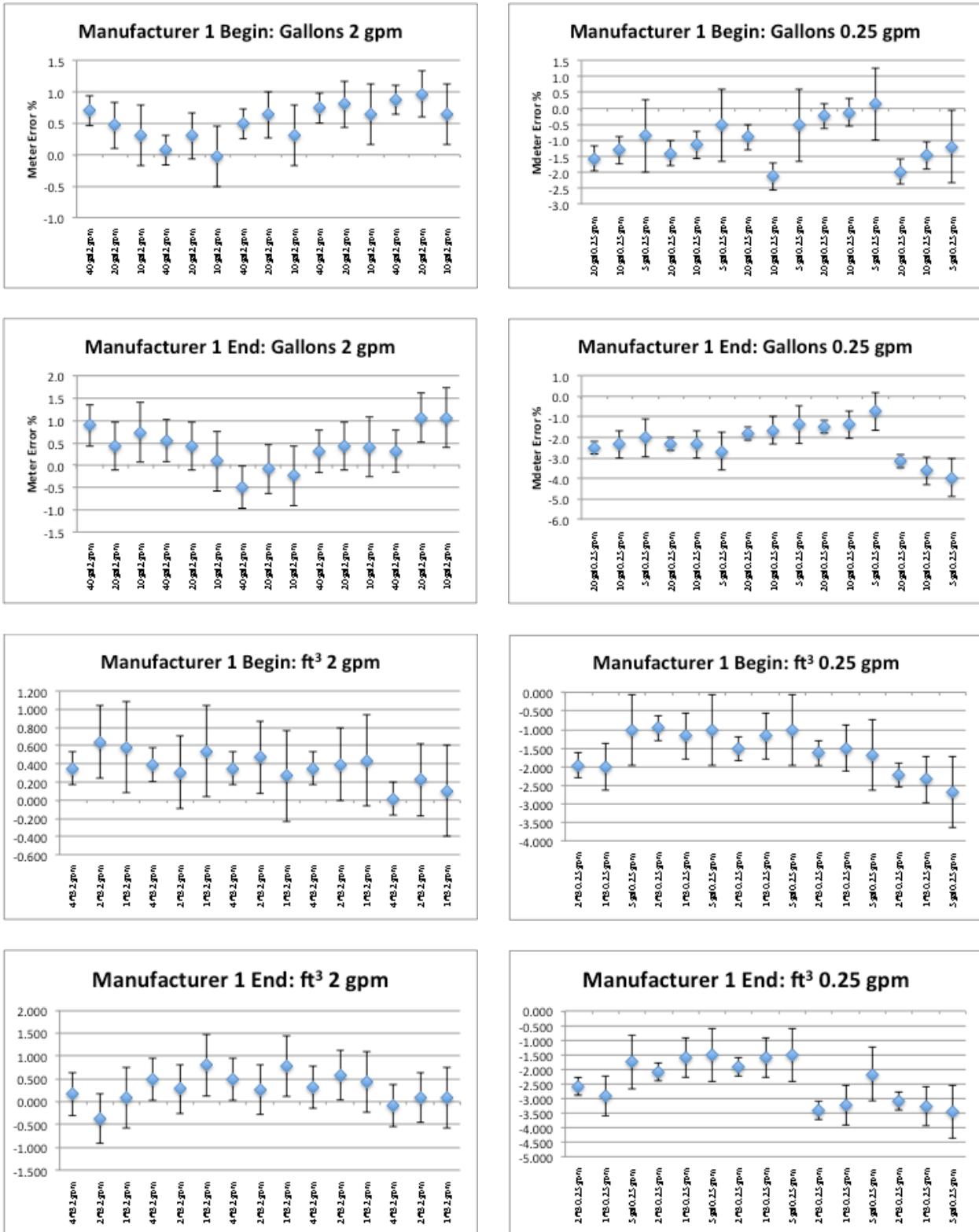
Manufacturer Results for Different Test Drafts at Same Flow Rates

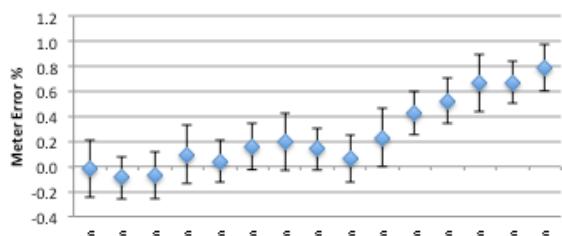
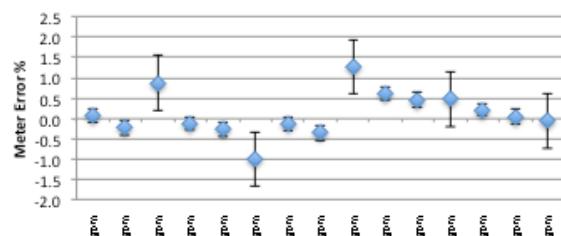
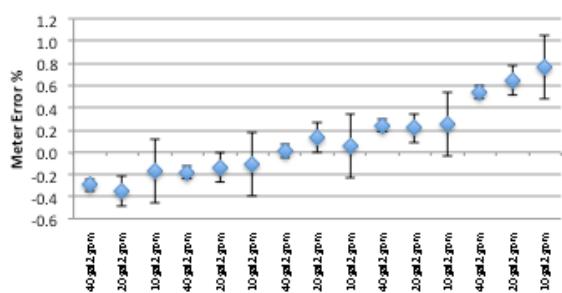
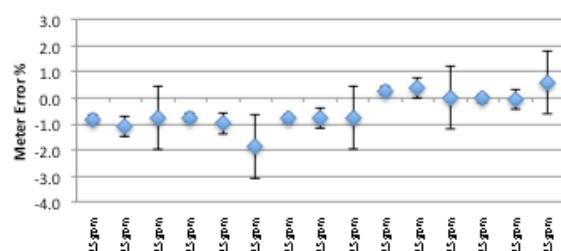
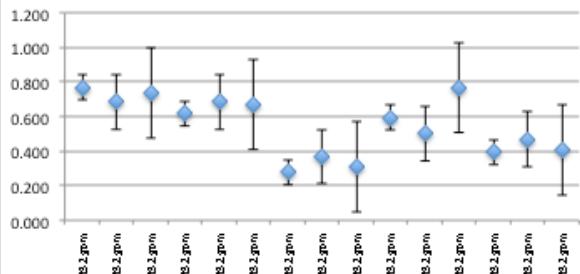
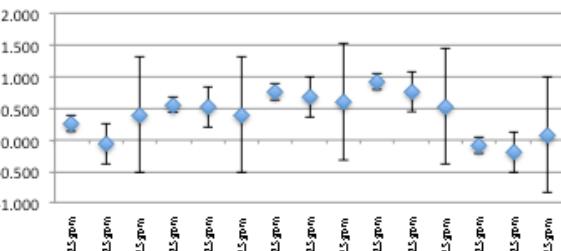
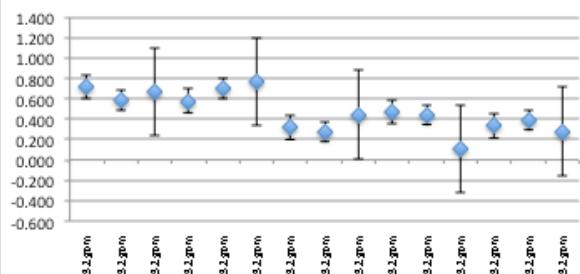
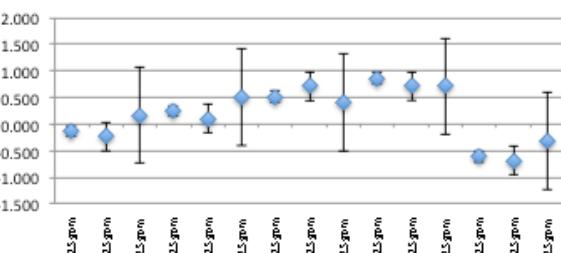
The manufacturers' average results for multiple test drafts at the same flow rates are graphed below with error bars calculated for the 95% confidence interval. This provides an indication of the agreement that can be expected for the results of different sizes of the test drafts for each flow rate using the same test system. There may be differences in the reference standards (scales) used in the gravimetric tests for the different sizes of test drafts. Also, there may have been differences in the sources of water, e.g., some tests may have used water from the city water supply and other tests may have used water in a recirculating water system. The charts show that the results agree quite well.

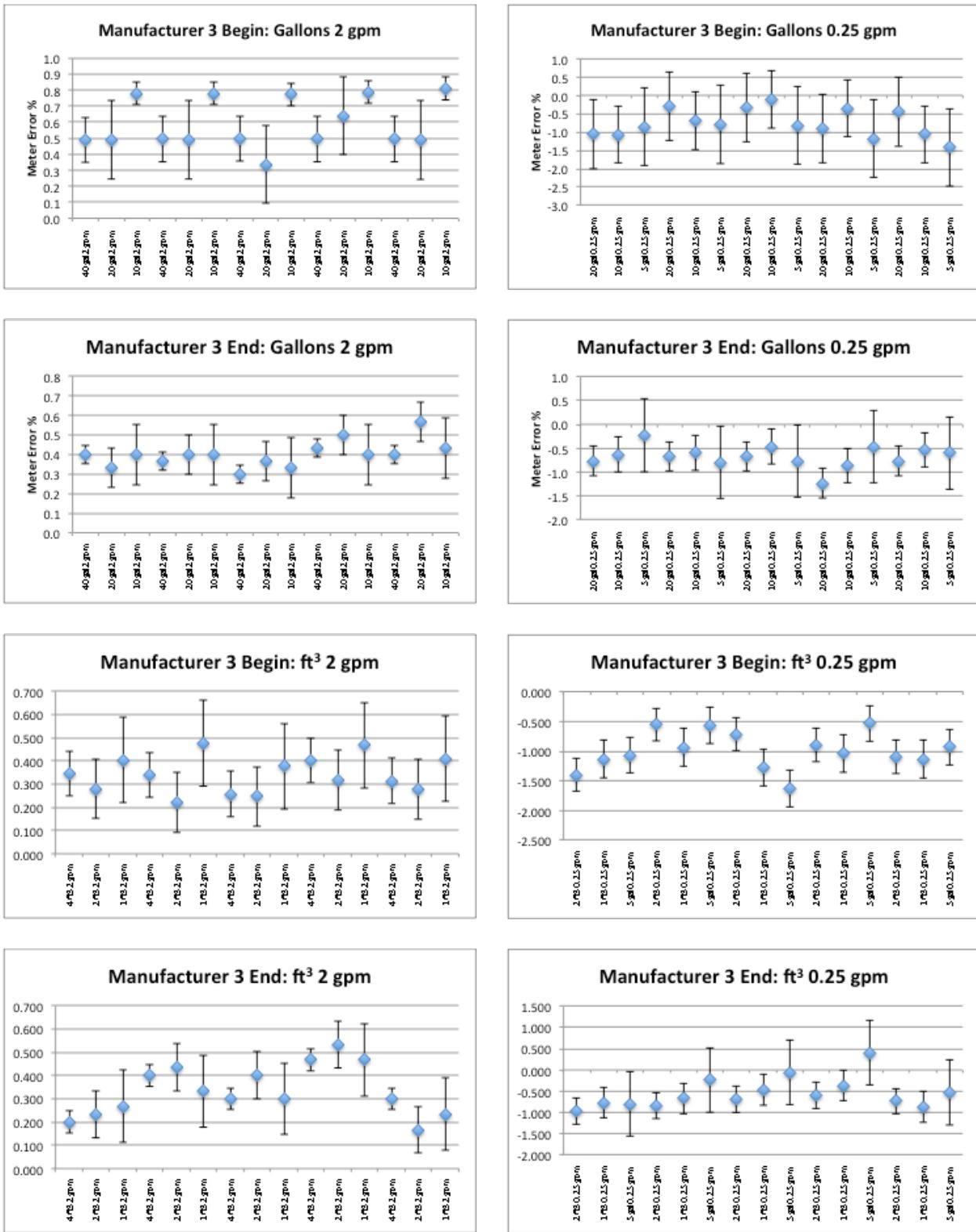
Each group of three consecutive values plotted on each graph represent one meter. Hence, for each manufacturer, the results for five meters at the same flow rate are shown on each graph. The initial tests of the gallon meters of manufacturer 3 at the 2-gpm flow rate for the 10-gal test draft seem inconsistent with the other test results.

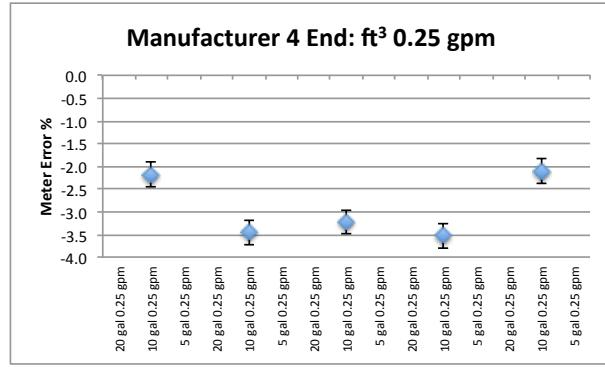
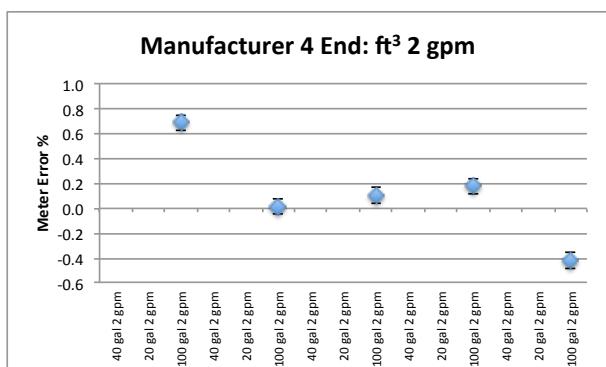
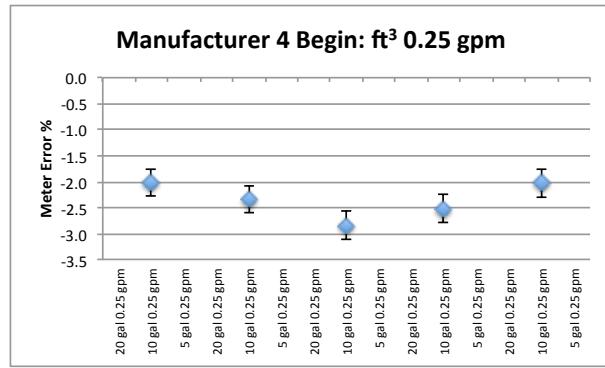
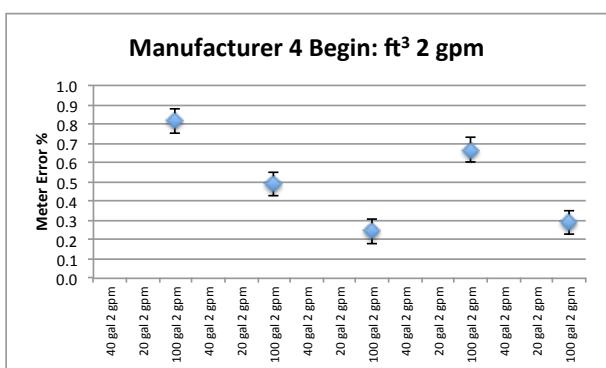
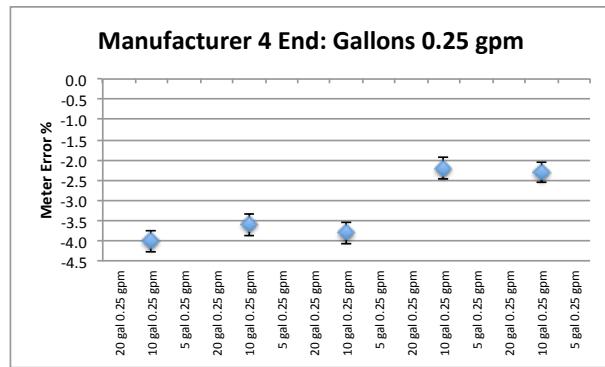
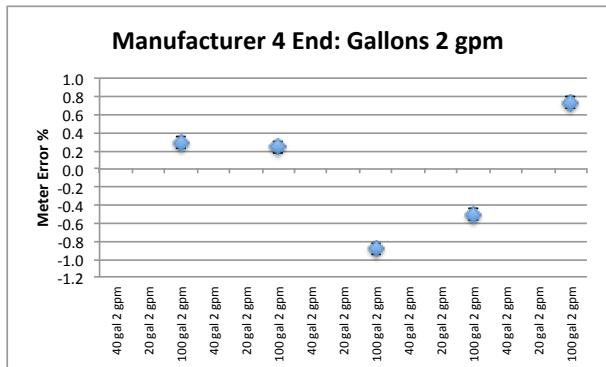
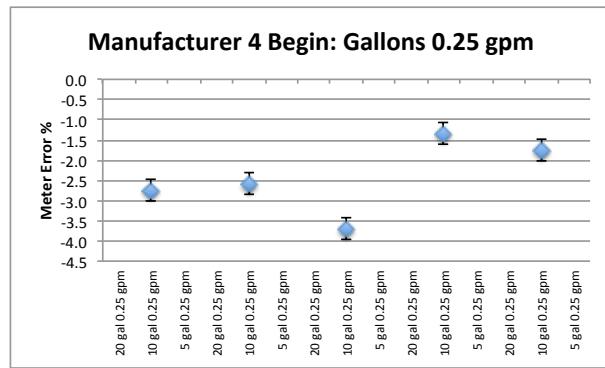
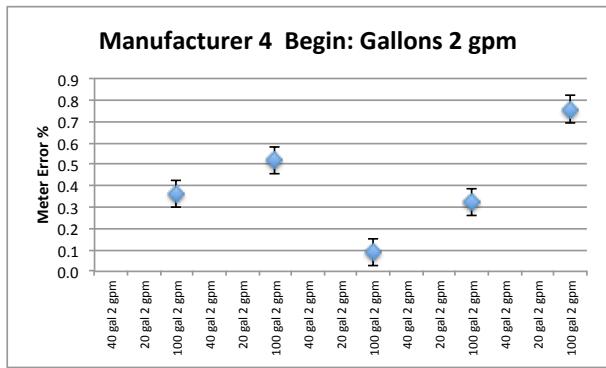
The initial test results at the start of the survey and the final results at the end of the survey are shown for each manufacturer. Consequently, there are four charts for the meters with gallon registers (two for the initial test results and two for the end test results) and four charts for the meters with registers indicating in cubic feet. Pooled standard deviations are computed for each manufacturer lab for the individual test results for each group of meters for each flow rate and size of test draft. There are four pooled standard deviations for each flow rate and size of test draft for each manufacturer; one each at the beginning and end for

the manufacturers for the meters indicating in gallons and one each at the beginning and end for the manufacturers for the meters indicating in cubic feet. These pooled standard deviations are used to compute the 95% confidence level error bars for the average results at the beginning and the end for each meter for each lab. Consequently, for a given meter the average percent meter error is plotted as shown by the diamond icon, but the pooled standard deviation for all five meters at a given flow rate and size of test draft is used to compute the confidence intervals for all five meters shown on the charts.



Manufacturer 2 Begin: Gallons 2 gpm**Manufacturer 2 Begin: Gallons 0.25 gpm****Manufacturer 2 End: Gallons 2 gpm****Manufacturer 2 End: Gallons 0.25 gpm****Manufacturer 2 Begin: ft³ 2 gpm****Manufacturer 2 Begin: ft³ 0.25 gpm****Manufacturer 2 End: ft³ 2 gpm****Manufacturer 2 End: ft³ 0.25 gpm**





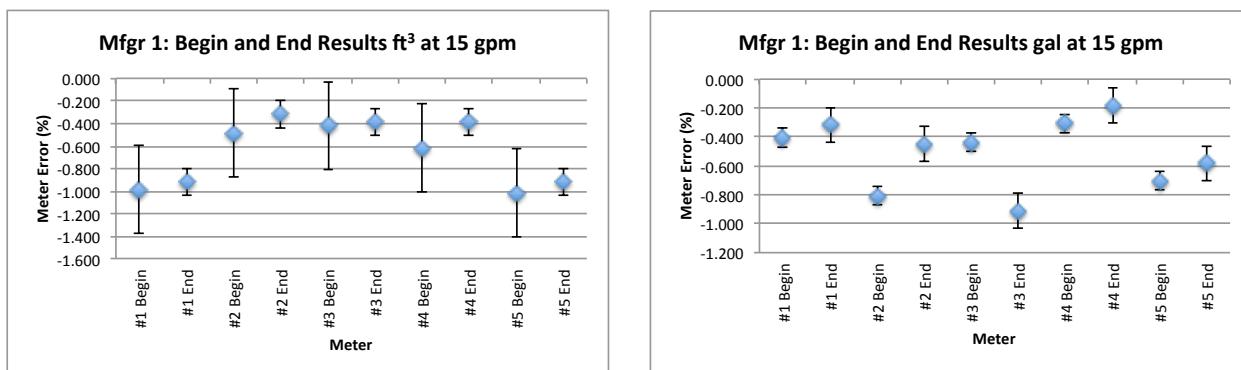
Comparison of Manufacturer Results: Beginning and End

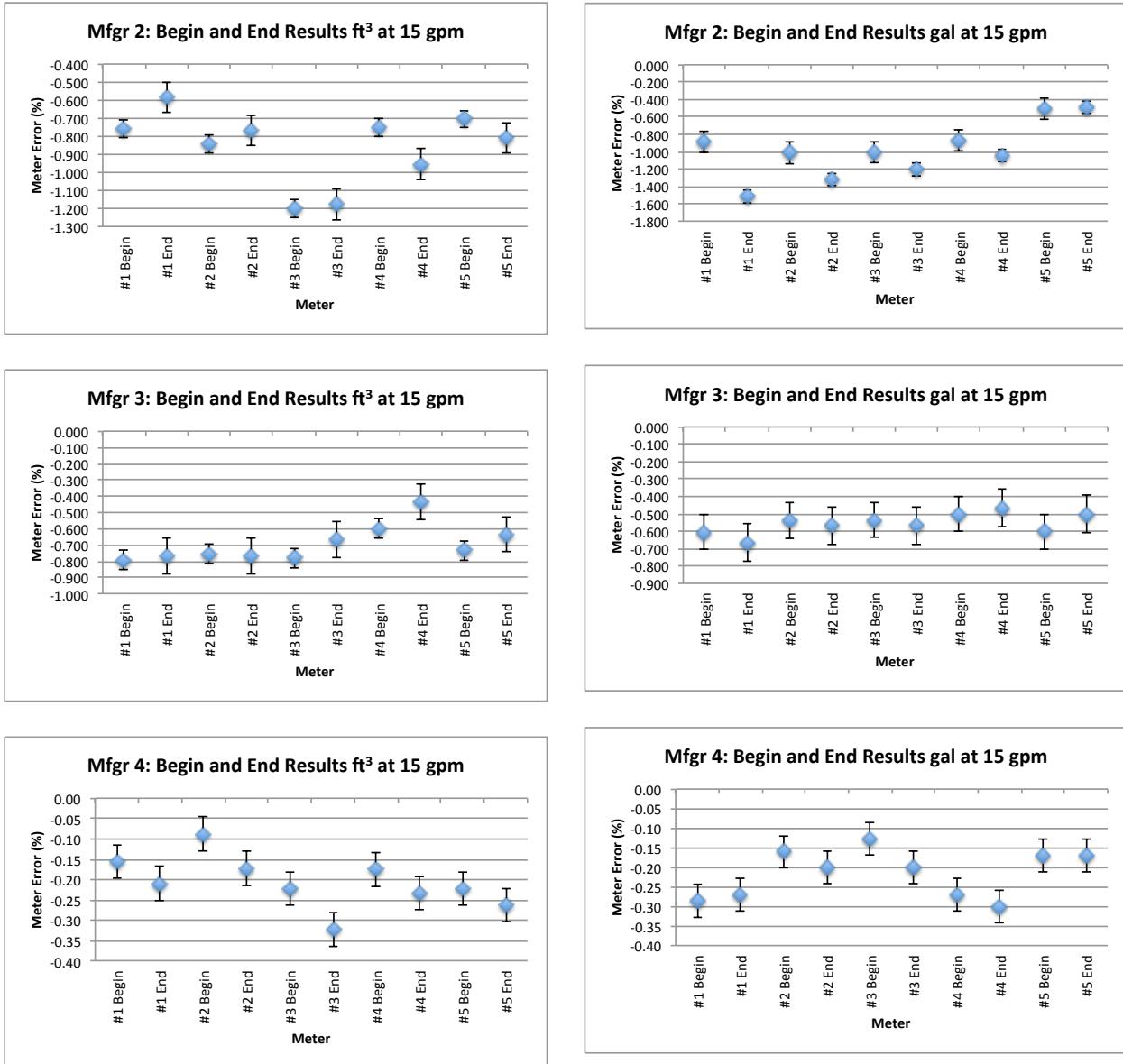
All of the manufacturers tested their meters at the beginning and the end of the survey. Three of the four manufacturers ran three repeat tests on each meter at different flow rates and different sizes of test drafts. The fourth manufacturer ran three repeat tests at the beginning of the survey at one test draft at each flow rate and one test at each flow rate at the end of the survey. Below is a table that shows the tests run by the manufacturers at the beginning and the end of the survey.

Flow Rate (gpm)	Manufacturers 1, 2, 3		Manufacturer 4
	Meters in ft ³	Meters in gal	ft ³ and gal
15	5	50	100 gal
2	4	40	
2	2	20	100 gal
2	1	10	
0.25	2	20	
0.25	1	10	10 gal
0.25	0.5	5	

The average meter results with the associated uncertainty at the 95% confidence level are shown below for each meter from each manufacturer. This information is helpful to establish the repeatability that can be expected for each brand of meter (when tested approximately six months apart), because each manufacturer tested the meters under the same test conditions. Additionally, manufacturers 1, 2 and 3 conducted the most sets of tests at the flow rates of 2 and 0.25 gpm using different sizes of test drafts.

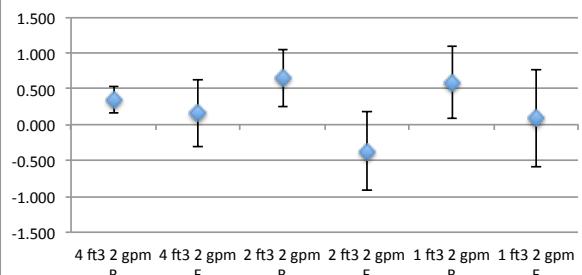
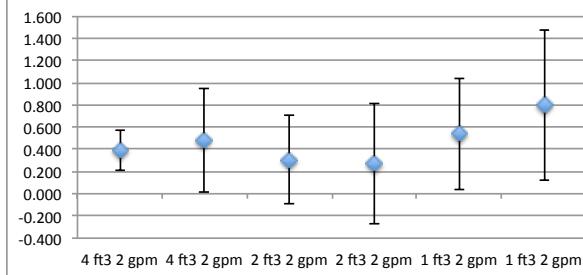
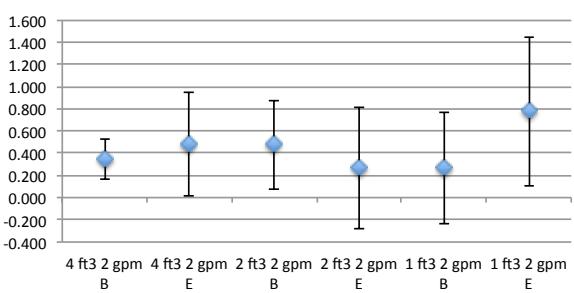
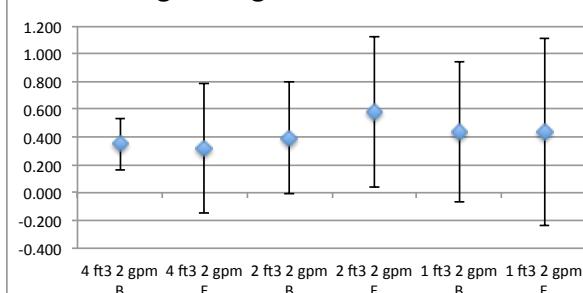
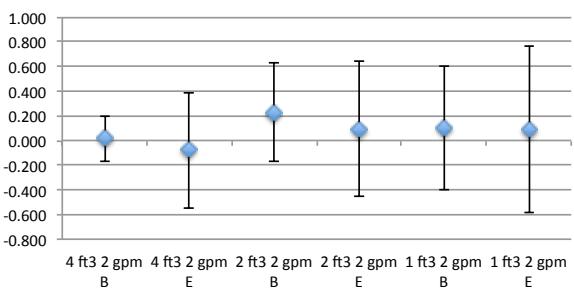
Since only one test draft size was used at the flow rate of 15 gpm, the meter errors as determined by the manufacturers at the beginning and the end of the survey are shown on the charts below. For each manufacturer, there is one chart for meters indicating in cubic feet and one chart for meters indicating in gallons. The beginning and end meter errors for all five meters for each manufacturer are shown on each chart. Since manufacturer 4 ran only one test at each flow rate at the end of the survey, the uncertainty limits from the tests run at the beginning of the survey were also used for the end results.

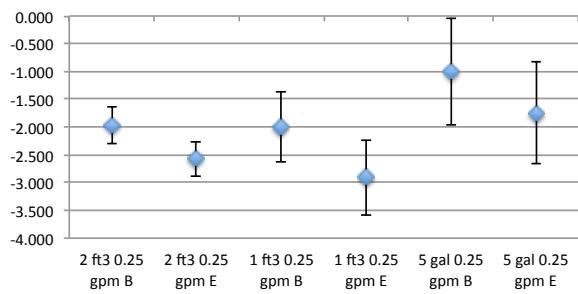
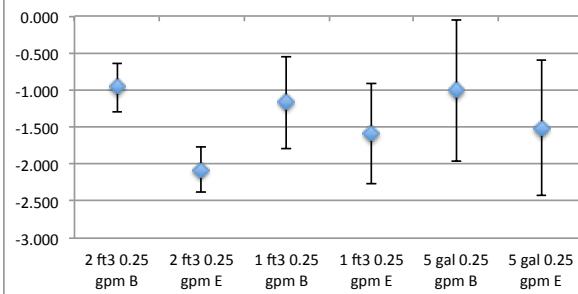
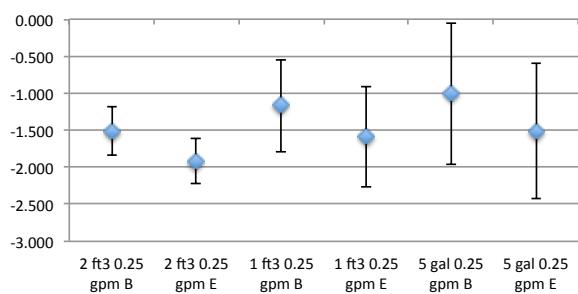
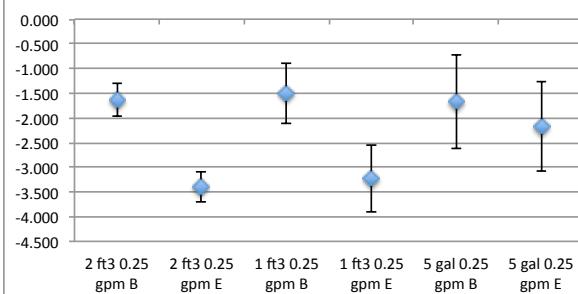
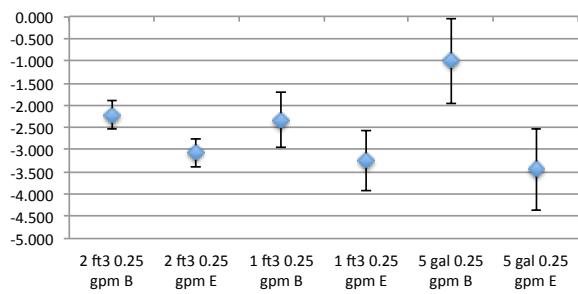


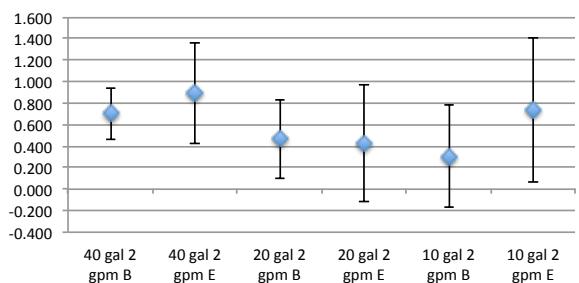
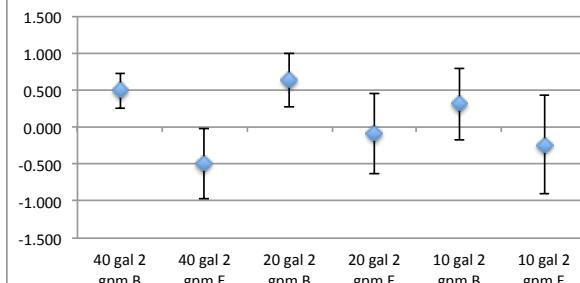
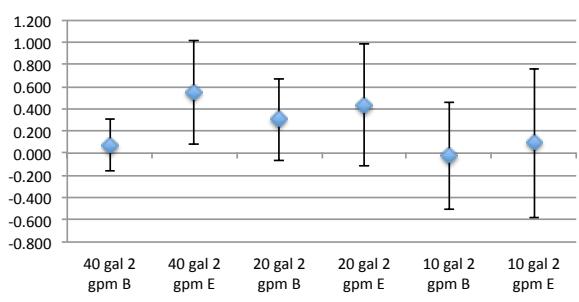
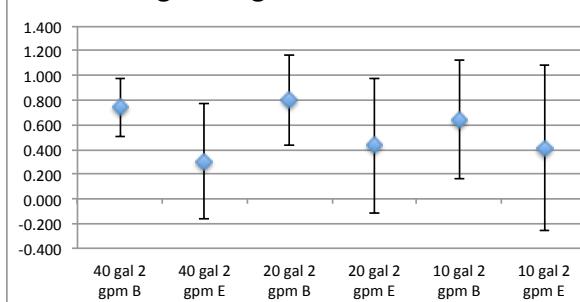
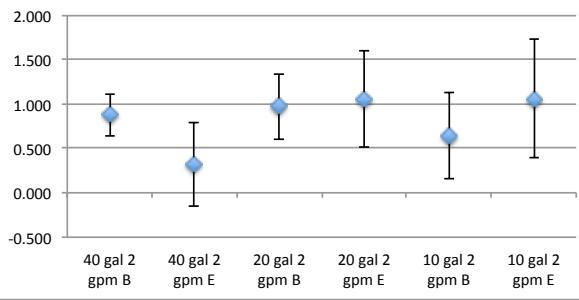


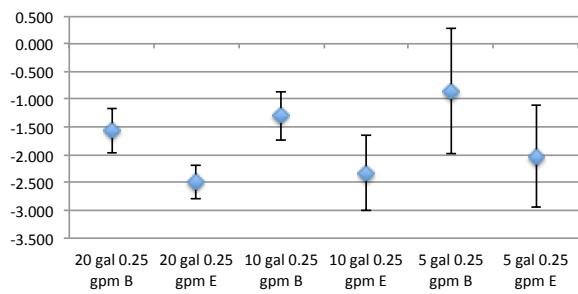
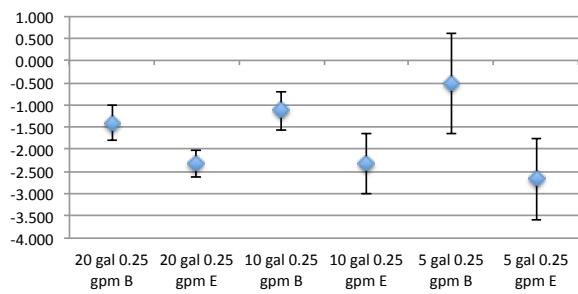
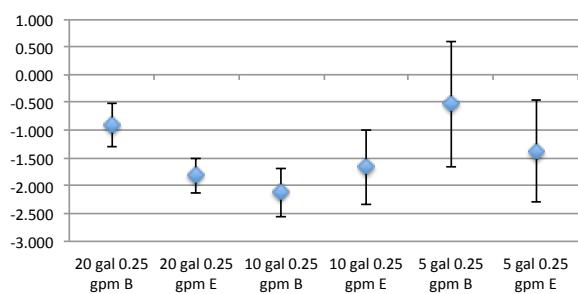
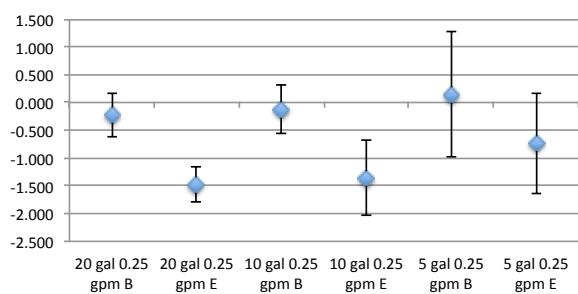
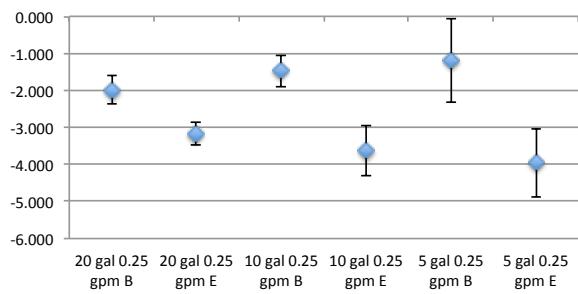
For the following charts, there are four sets of five graphs for manufacturers 1, 2 and 3. Each graph represents the results for one meter at the flow rates of 2 and 0.25 gpm for each size test draft with the beginning and the end results graphed in sequence for each flow rate. The values for the x-axes correspond to meters indicating in cubic feet or gallons. The first two sets of graphs for each manufacturer is for meters indicating in cubic feet; the second set is for meters indicating in gallons. Each graph shows the test results at a single flow rate for the different sizes of test drafts for the flow rate. The graphs show that some of the uncertainty limits for each meter at a particular flow rate for the same size of test draft do not overlap. The reasons that some of the results do not overlap are not clear, but it is likely that the accuracy for a few meters from one manufacturer changed between the time of the initial tests and the final tests performed by the manufacturer.

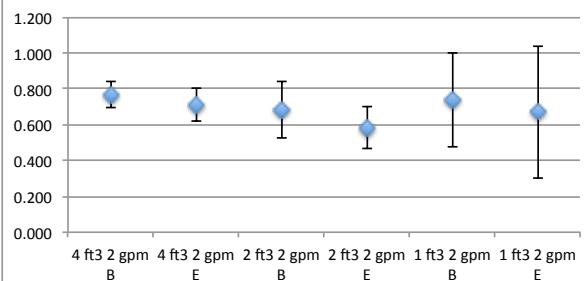
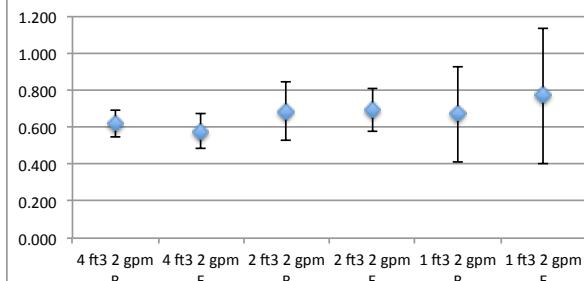
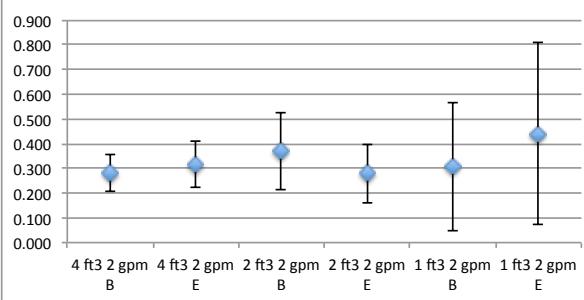
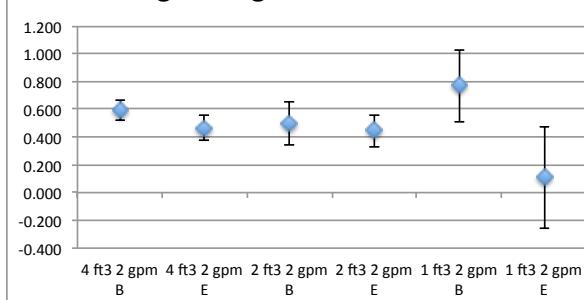
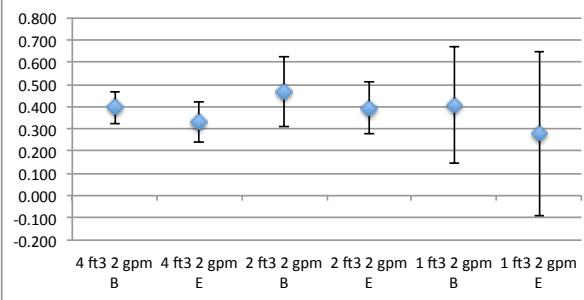
Because manufacturer 4 tested each meter at only one size test draft at each flow rate, the results for all meters are shown on one graph for each flow rate for meters indicating in cubic feet and another chart for meters indicating in gallons, analogous to the charts above at the flow rate of 15 gpm.

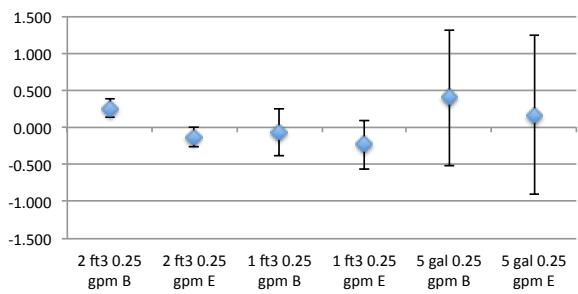
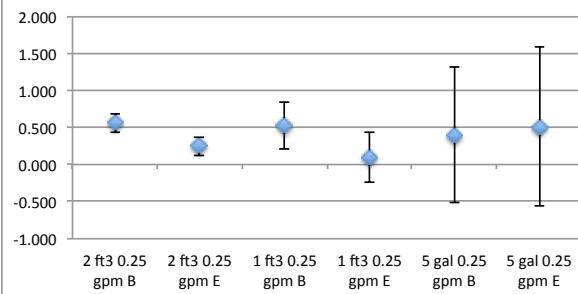
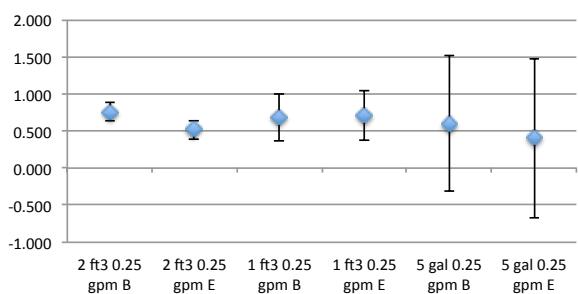
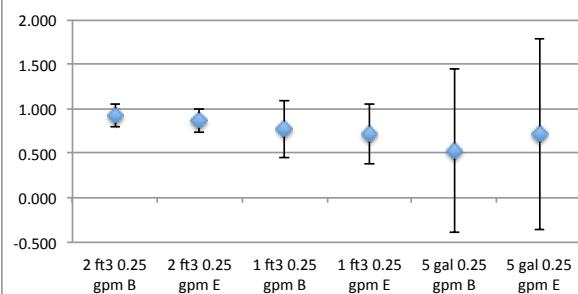
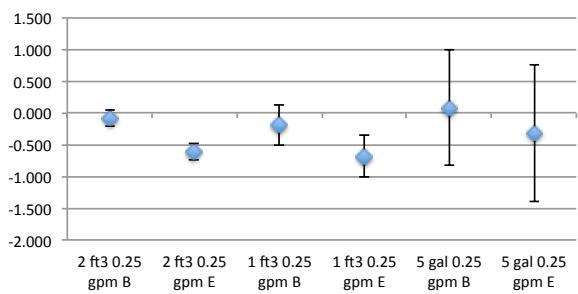
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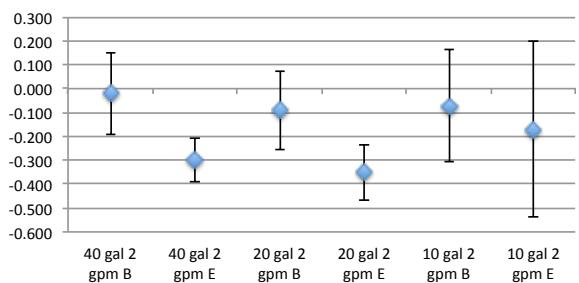
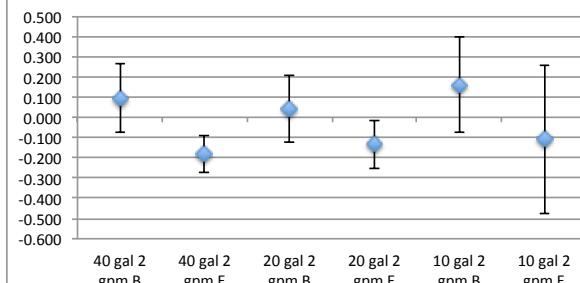
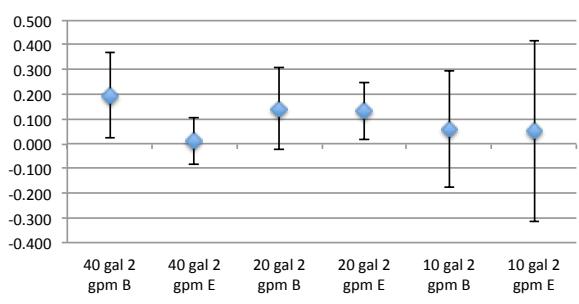
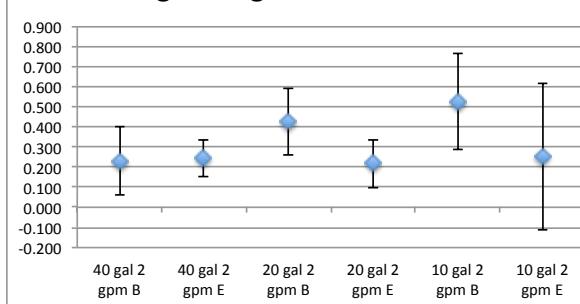
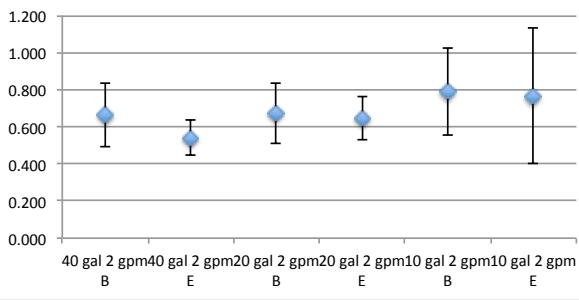
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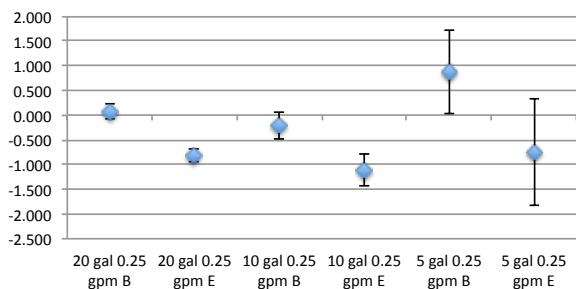
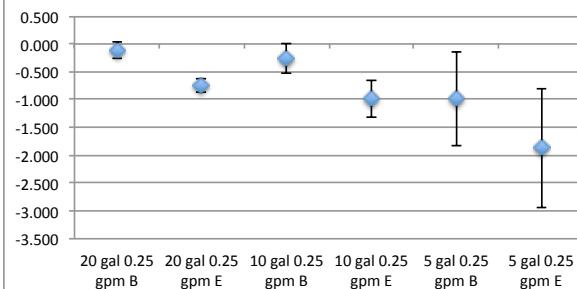
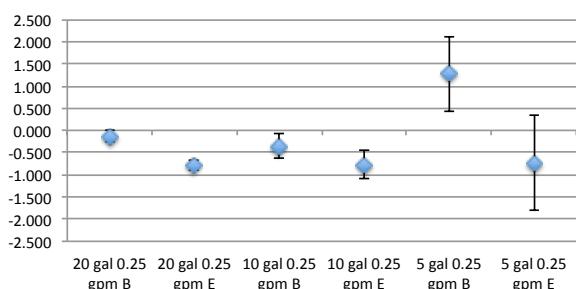
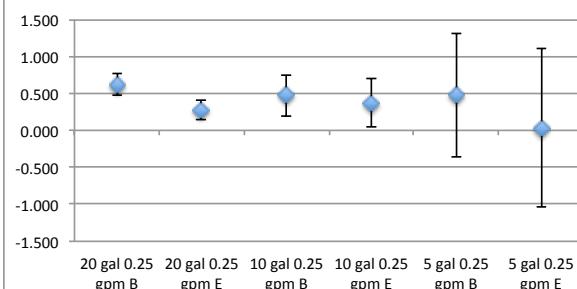
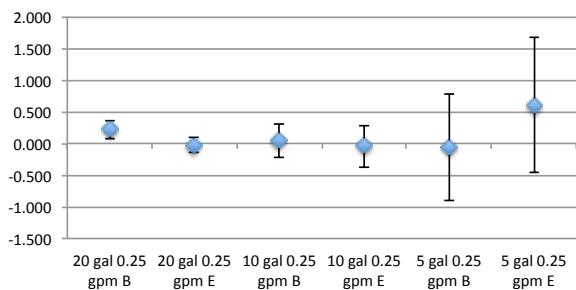
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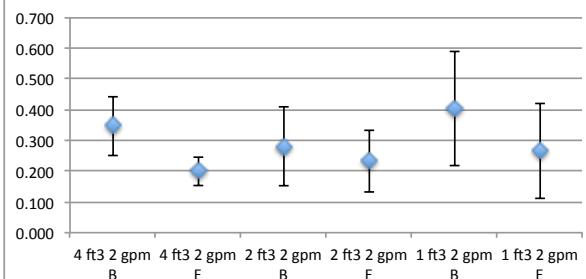
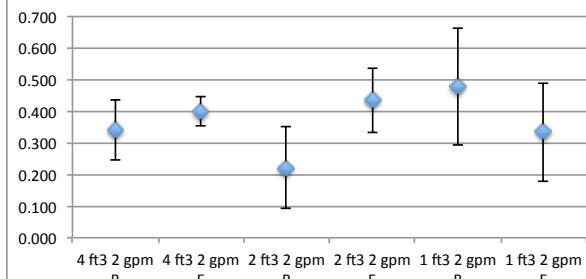
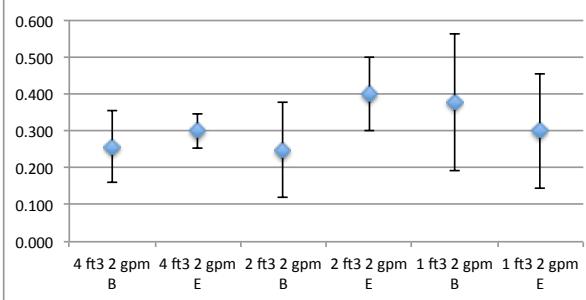
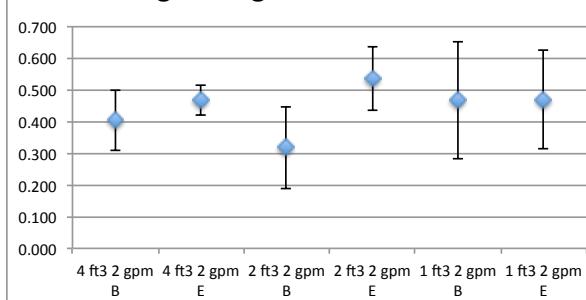
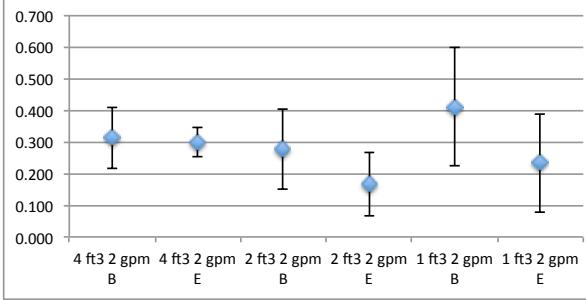
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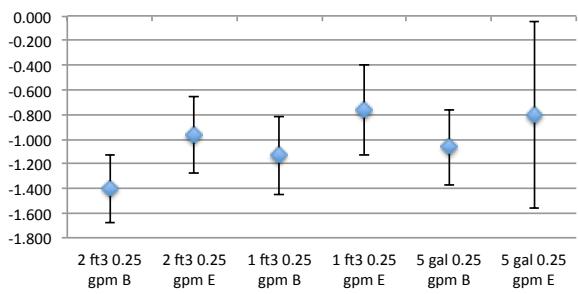
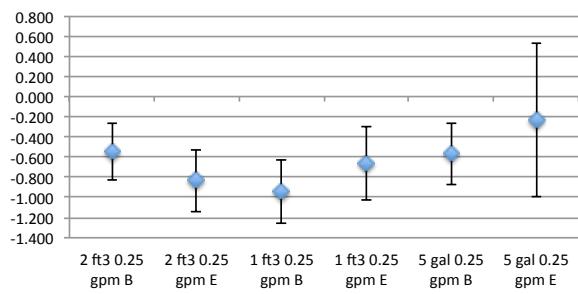
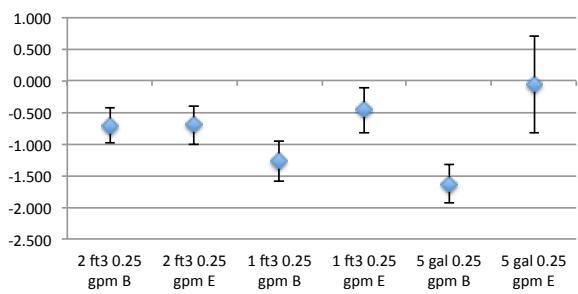
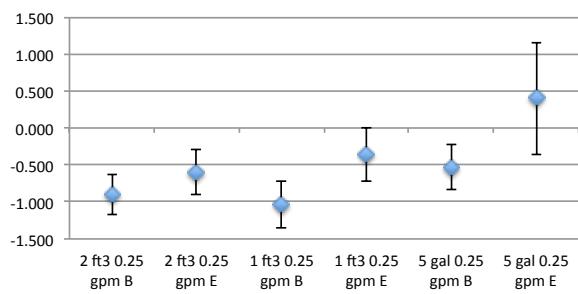
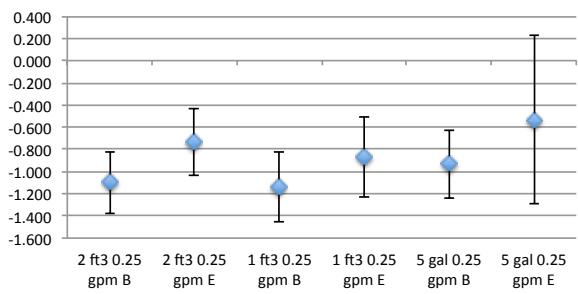
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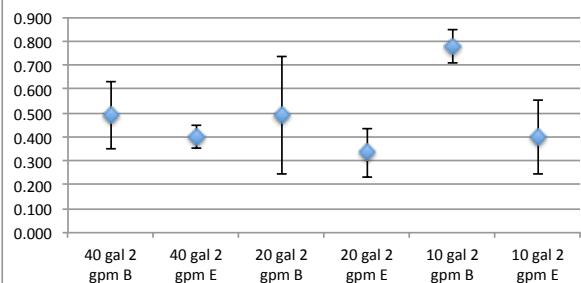
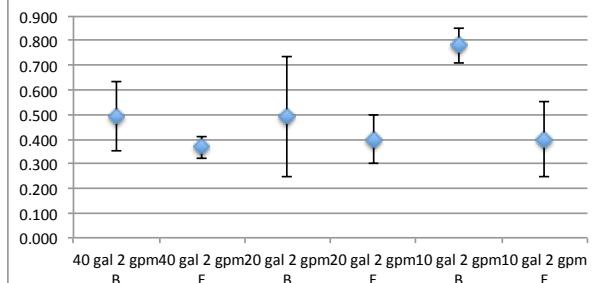
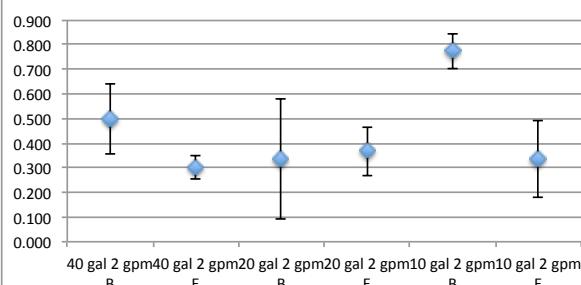
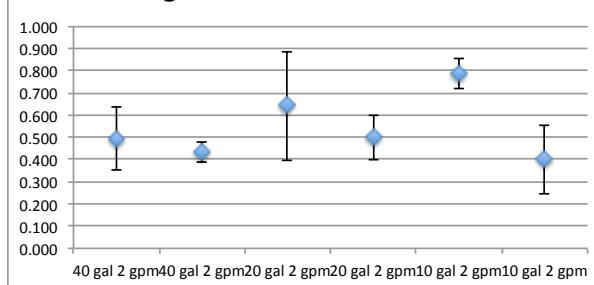
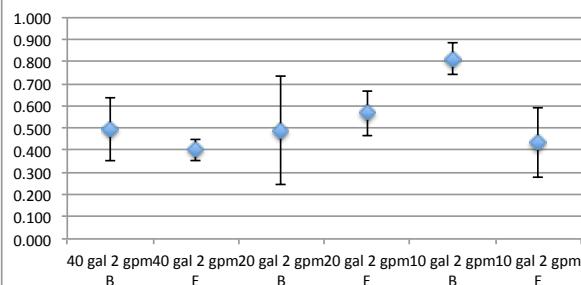
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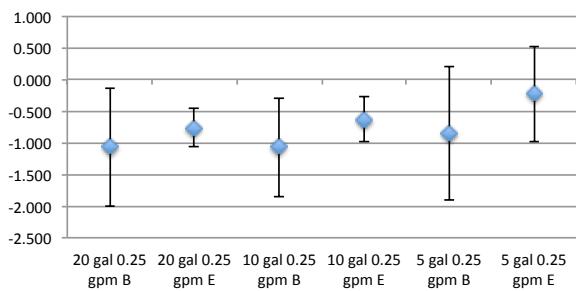
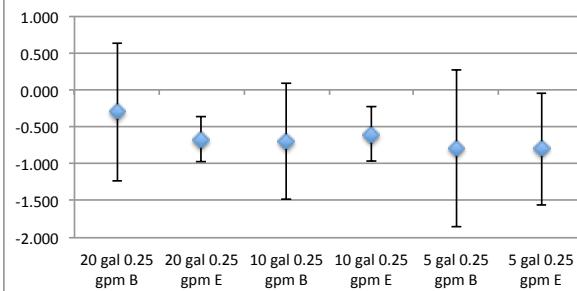
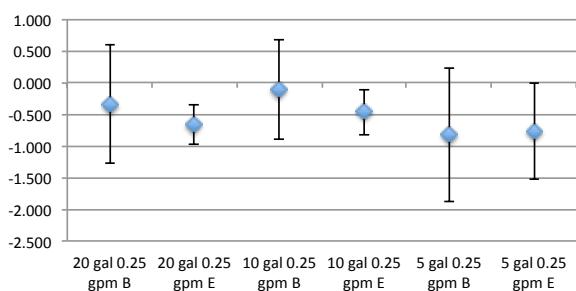
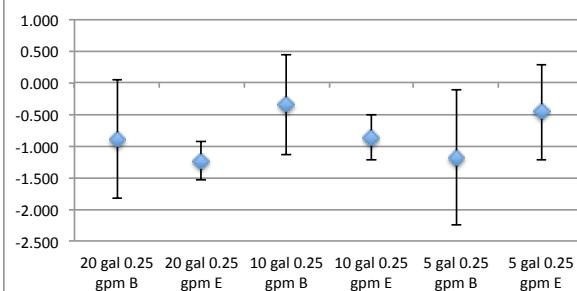
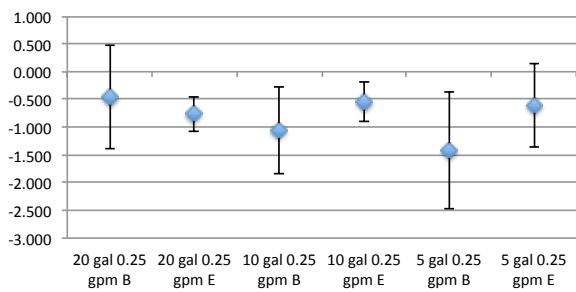
Mfgr 2: Begin and End Results**Mfgr 2: Begin and End Results****Mfgr 2: Begin and End Results****Mfgr 2: Begin and End Results****Mfgr 2: Begin and End Results**

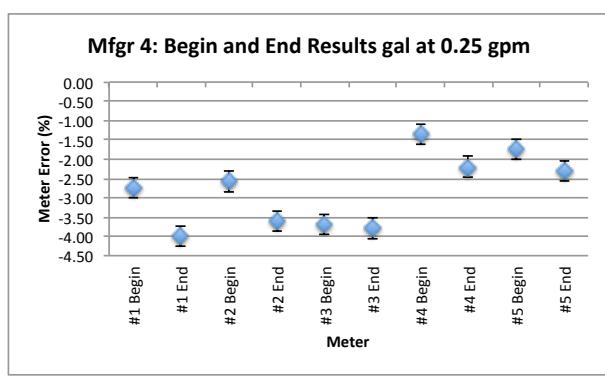
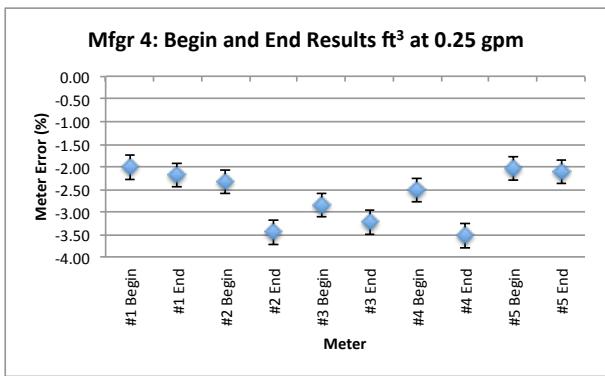
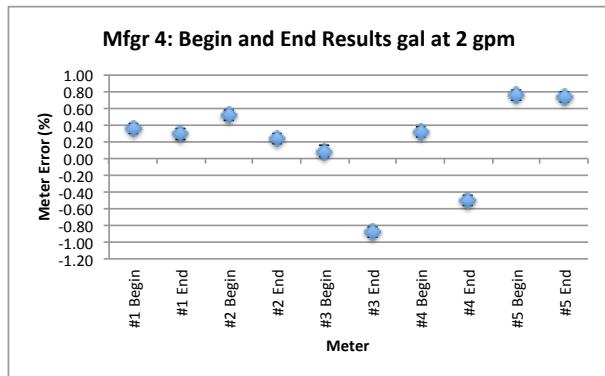
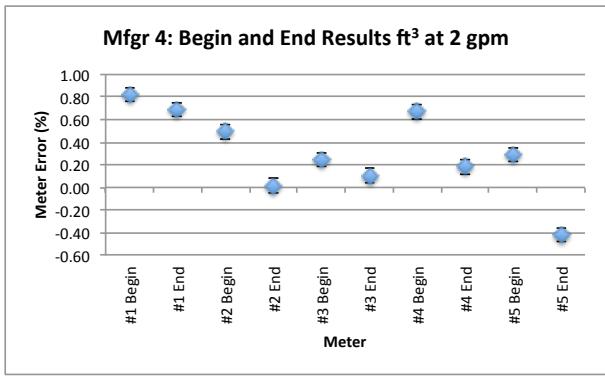
Mfgr 2: Begin and End Results**Mfgr 2: Begin and End Results****Mfgr 2: Begin and End Results****Mfgr 2: Begin and End Results****Mfgr 2: Begin and End Results**

Mfgr 3: Begin and End Results**Mfgr 3: Begin and End Results****Mfgr 3: Begin and End Results****Mfgr 3: Begin and End Results****Mfgr 3: Begin and End Results**

Mfgr 3: Begin and End Results**Mfgr 3: Begin and End Results****Mfgr 3: Begin and End Results****Mfgr 3: Begin and End Results****Mfgr 3: Begin and End Results**

Mfgr 3: Start and End Results**Mfgr 3: Start and End Results****Mfgr 3: Start and End Results****Mfgr 3: Start and End Results****Mfgr 3: Start and End Results**

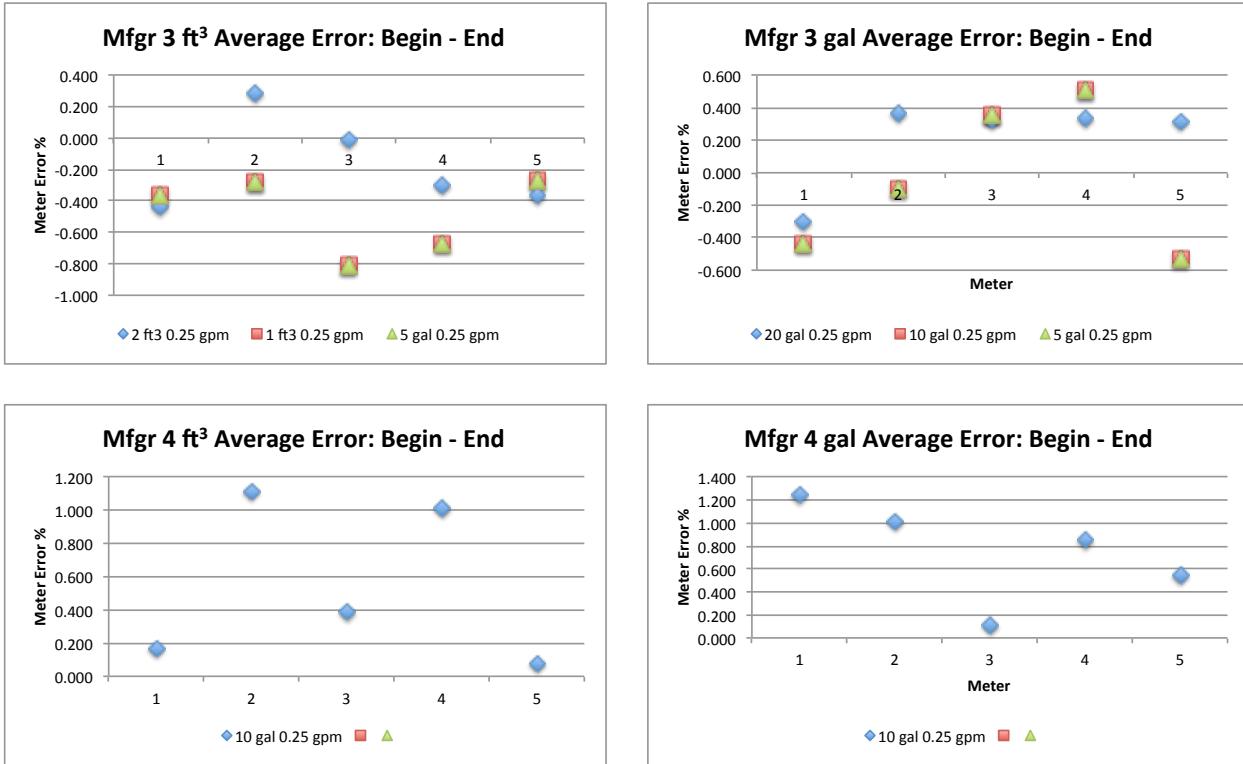
Mfgr 3: Start and End Results**Mfgr 3: Start and End Results****Mfgr 3: Start and End Results****Mfgr 3: Start and End Results****Mfgr 3: Start and End Results**



Below are charts showing the average change in test results for each meter in each set of meters (i.e., meters indicating in gallons and cubic feet) for each manufacturer for the flow rate of 0.25 gpm. Only the results for the flow rate of 0.25 gpm are plotted, because I was advised that any change in meter accuracy is more likely to be evident at the minimum flow rate. The charts below should be used only to draw broad assessments of the trends and not to take the values themselves as specific, because when computing the differences in the numbers, the uncertainty associated with the calculated differences are the sums of the uncertainties associated with each individual value used in each calculation.

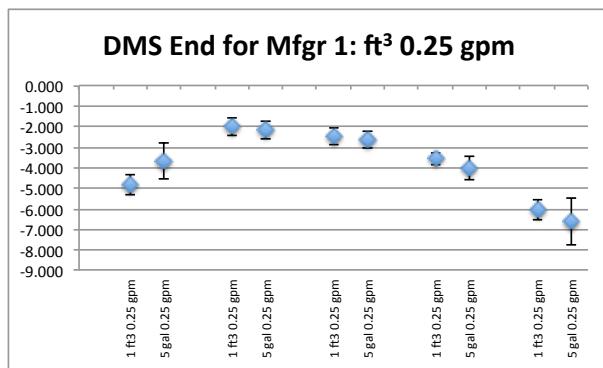
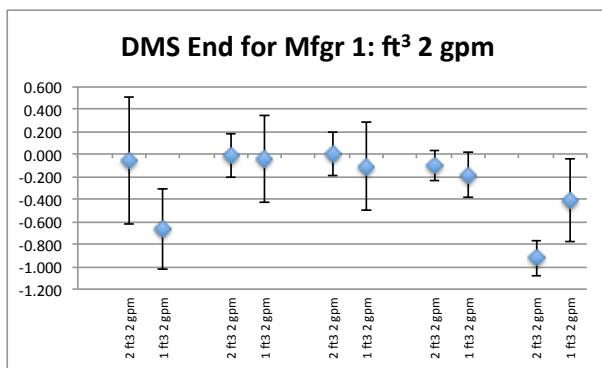
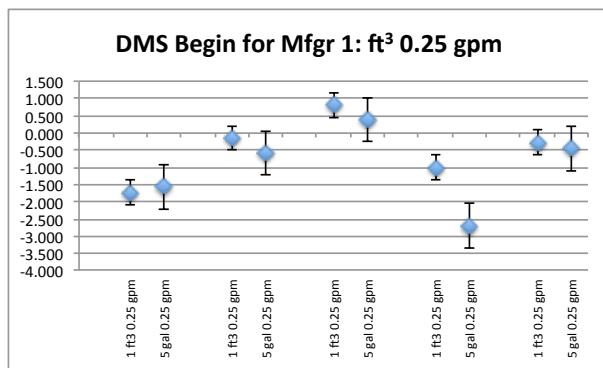
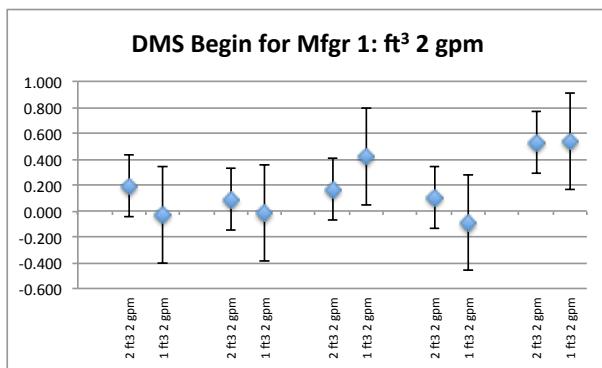
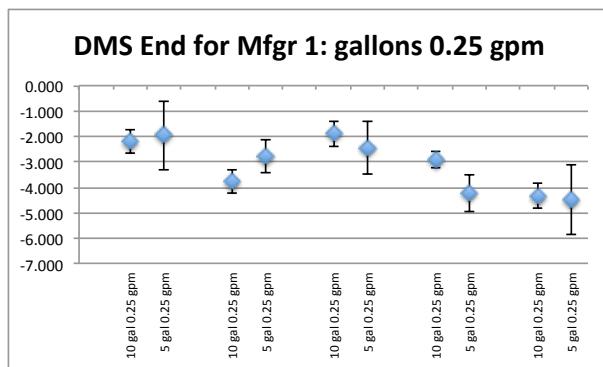
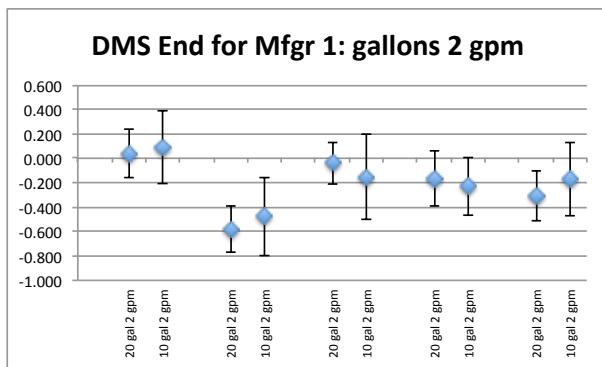
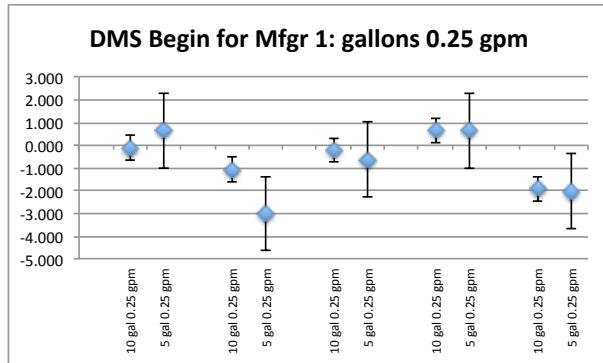
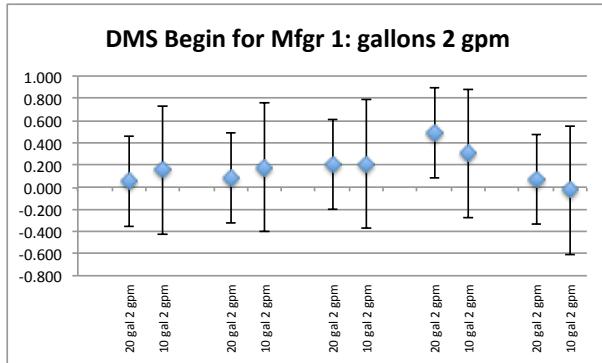
If the differences for the beginning and end sets of values are random, then the average for each manufacturer at each flow rate and size of test draft should be near zero. If the differences are significantly different from zero and primarily in one direction, then one can conclude that the accuracy of the meter probably changed in the time between the tests preformed by the manufacturers.

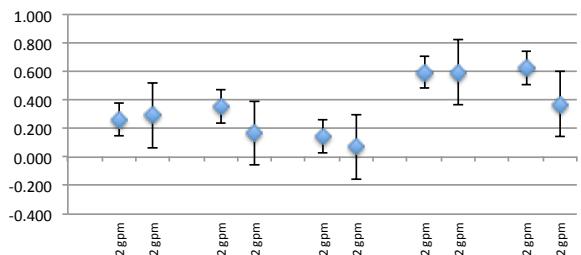
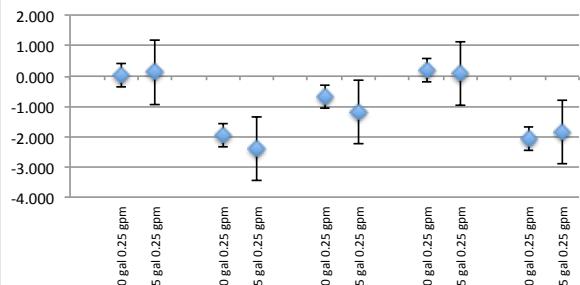
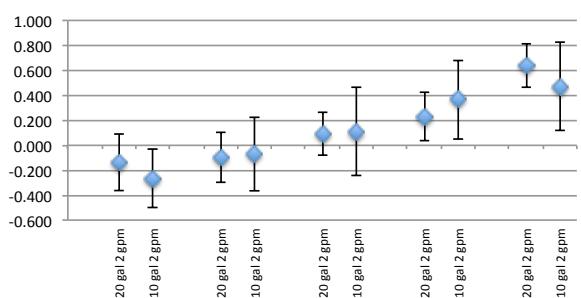
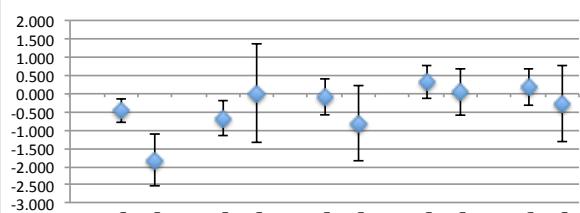
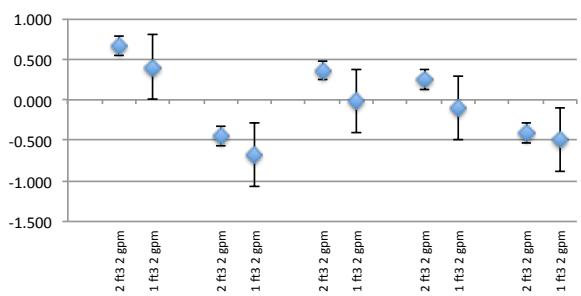
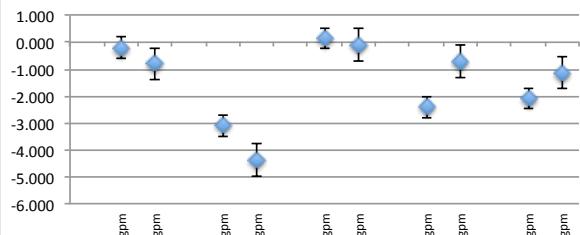
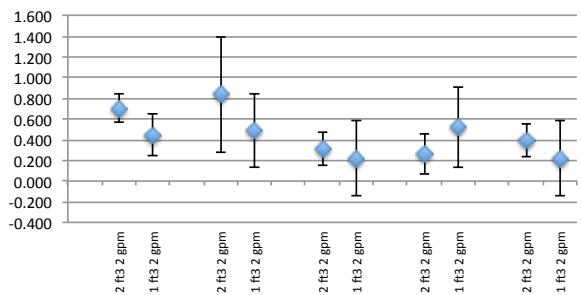
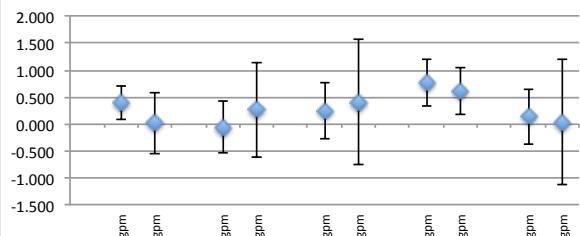


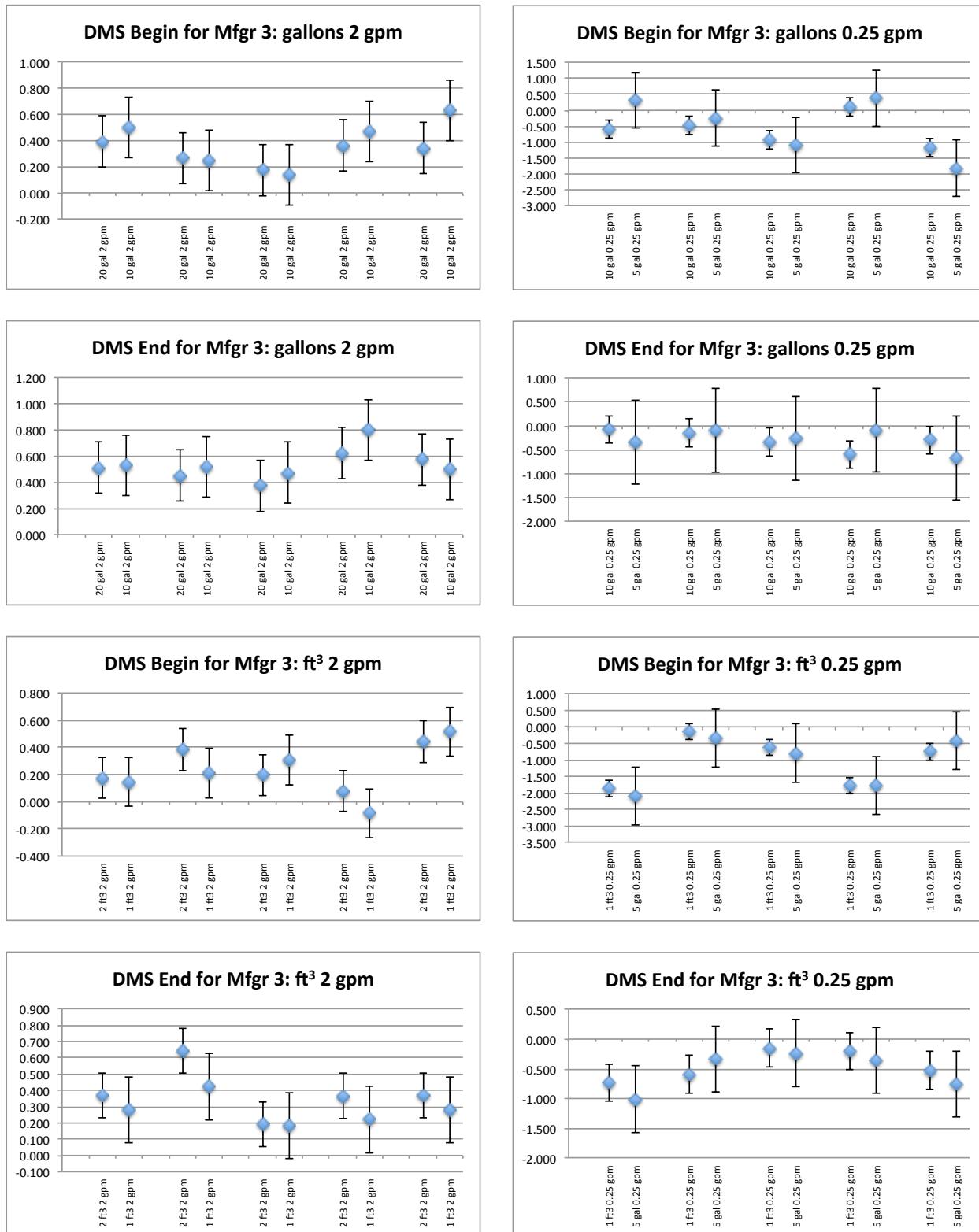


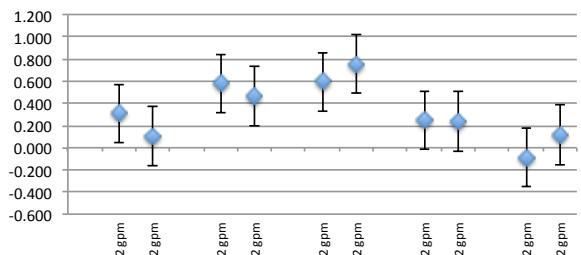
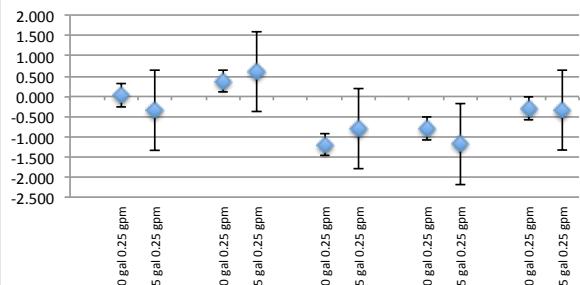
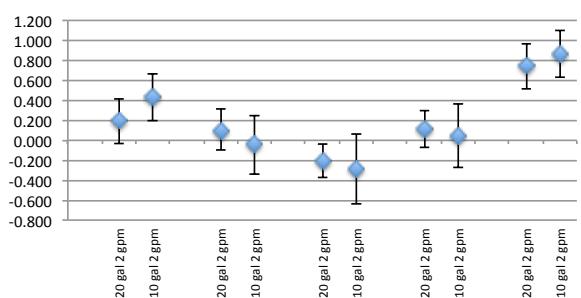
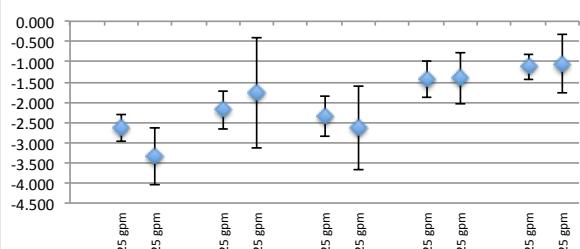
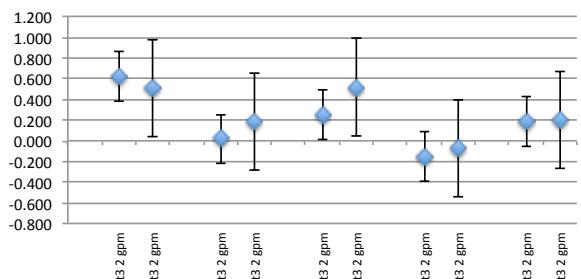
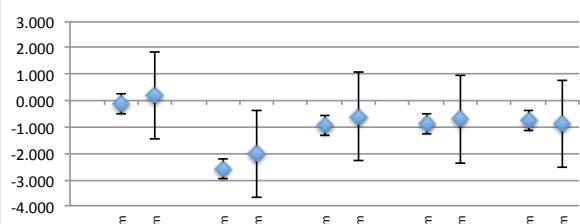
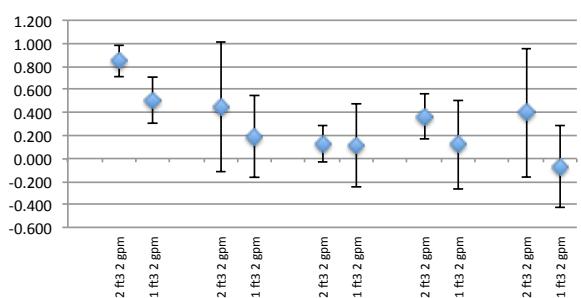
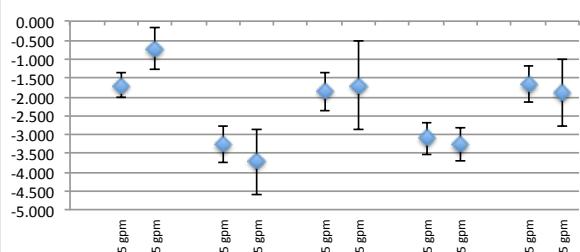
Based on the large percentage of meters for manufacturer 1 that show the difference between the beginning and end test results to be positive and the rather larger values for some of these differences, it is likely that some of the meters changed accuracy during the survey at the 0.25-gpm flow rate. For manufacturer 2, the differences between the beginning and end results are generally small relative to the uncertainty and there are some negative numbers on the charts. The meters for manufacturer 3 showed relatively small changes from the beginning to the end and some of the differences are negative. Hence, it appears that there were no significant changes in the accuracies of these meters. The meters for manufacturer 4 show differences that are all positive and some of the differences are near 1%. This gives the impression that the accuracies of some of these meters may have changed at the minimum flow rate, but the differences are smaller than for manufacturer 1.

DMS Results for Different Test Draft Sizes at Same Flow Rates



DMS Begin for Mfgr 2: gallons 2 gpm**DMS Begin for Mfgr 2: gallons 0.25 gpm****DMS End for Mfgr 2: gallons 2 gpm****DMS End for Mfgr 2: gallons 0.25 gpm****DMS Begin for Mfgr 2: ft³ 2 gpm****DMS Begin for Mfgr 2: ft³ 0.25 gpm****DMS End for Mfgr 2: ft³ 2 gpm****DMS End for Mfgr 2: ft³ 0.25 gpm**



DMS Begin for Mfgr 4: gallons 2 gpm**DMS Begin for Mfgr 4: gallons 0.25 gpm****DMS End for Mfgr 4: gallons 2 gpm****DMS End for Mfgr 4: gallons 0.25 gpm****DMS Begin for Mfgr 4: ft³ 2 gpm****DMS Begin for Mfgr 4: ft³ 0.25 gpm****DMS End for Mfgr 4 : ft³ 2 gpm****DMS End for Mfgr 4: ft³ 0.25 gpm**

Variations in Repeatability for Different Sizes of Test Drafts

It is interesting to examine the pooled standard deviations for the same flow rates, but for the different sizes of the test drafts for the data obtained by the manufacturers and DMS. The standard deviations for the meters registering in gallons and cubic feet for the tests at the same flow rate and comparable test draft sizes were pooled as measures of the variances for:

1. Each manufacturer's results at the start of the survey;
2. Each manufacturer's results at the end of the survey;
3. The DMS results for each manufacturers' set of meters at the start of the survey; and
4. The DMS results for each group of meters (mixed sets of meters) at the end of the survey.

Below is a table of the pooled standard deviations obtained by the laboratories of the manufacturers and DMS.

Pooled Standard Deviations

Meter Set	50 gal 15 gpm	40 gal 2 gpm	20 gal 2 gpm	10 gal 2 gpm	20 gal 0.25 gpm	10 gal 0.25 gpm	5 gal 0.25 gpm
Mfgr Begin	0.082	0.115	0.187	0.134	0.658	0.570	0.746
Mfgr Begin	0.266	0.203	0.367	0.471	0.348	0.513	1.000
Mfgr Begin	0.107	0.195	0.159	0.203	0.147	0.222	0.728
Mfgr End	0.110	0.045	0.097	0.148	0.294	0.346	0.725
Mfgr End	0.103	0.104	0.661	0.799	0.341	0.793	0.451
Mfgr End	0.081	0.112	0.094	0.415	0.096	0.259	0.868
DMS by Mfgr	0.164		0.188	0.221		0.276	0.838
DMS by Mfgr	0.091		0.229	0.357		0.344	0.618
DMS by Mfgr	0.028		0.117	0.376		0.377	0.567
DMS Mixed	0.031		0.218	0.223		0.309	0.682
DMS Mixed	0.038		0.537	0.339		0.457	0.837
DMS Mixed	0.270		0.132	0.195		0.303	0.533

Repeatability Expressed in Units of Volume

In this survey, the percent errors for the meter results were calculated by dividing the measured difference between the meter indications and the volume of water contained in the reference standard and dividing the difference by the nominal size of the test draft. The variation in the test results expressed in the percent meter error for repeat tests at the same flow rate, but for different sizes of test drafts, makes the assessment of the variation in test results more difficult, because the percent meter errors are affected by the sizes of the test drafts. The appropriate way to understand the repeatability of the test results is to express the repeatability in units of volume.

Using the manufacturers' pooled standard deviations for the percent error for each size test draft at the beginning and the end of the survey, the standard deviations were converted into volume units (cubic inches).

Below are the pooled standard deviations in cubic inches for the three manufacturers that performed three tests at each flow rate and each test draft size at the **beginning** of the survey. The pooled standard deviations for meters indicating in gallons are given in the top half of the table and the meters indicating in cubic feet are in the bottom half of the table.

Meter Set	50 gal 15 gpm	40 gal 2 gpm	20 gal 2 gpm	10 gal 2 gpm	20 gal 0.25 g	10 gal 0.25 g	5 gal 0.25 gpm
Mfgr	13.6	20.4	7.5	4.1	7.2	4.1	7.4
Mfgr	11.7	12.4	10.8	1.6	41.2	17.3	11.7
Mfgr	7.2	20.9	16.2	10.6	17.4	9.5	12.5
Meter Set	5 ft3 15 gpm	4 ft3 2 gpm	2 ft3 2 gpm	1 ft3 2 gpm	2 ft3 0.25 gpm	1 ft3 0.25 gpm	0.5 ft3 0.25 gpm
Mfgr	4.0	4.9	5.2	4.3	4.1	5.2	7.6
Mfgr	4.9	6.4	4.2	3.1	9.2	5.2	2.5
Mfgr	32.0	12.2	13.2	8.3	10.9	10.3	7.9

The ratios of the sample variances (the squares of the standard deviations) for each size test draft at the same flow rate can be compared using the statistical F-test to determine the probability that the variances are equal. If the variances do not appear to be statistically equal at a 95% level of confidence, then one can conclude that the variances probably are not equal. The pooling of each set of data results in 10 degrees of freedom for each pooled standard deviation. The ratios of the variances for the different sets of data can be compared using the F-test. If the probability of the F-value lies in the tail of the F-distribution at a level of less than 5%, then the variances (standard deviations) are considered not equal.

Below are the corresponding probabilities that the pooled standard deviations are statistically the same. There are 10 degrees of freedom for each pooled standard deviation. The cells that indicate that there is less than a 5 percent probability that the two pooled standard deviations are the same are shaded red. There are 2 out of 36 F-tests that indicate that the standard deviations that were compared are unlikely to be the same at a 95% confidence level.

	2 gpm	2 gpm	2 gpm	0.25 gpm	0.25 gpm	0.25 gpm
Meter Set	40 to 20 gal	40 to 10 gal	20 to 10 gal	20 to 10 gal	20 to 5 gal	10 to 5 gal
Mfgr	1.000	1.000	0.995	0.992	0.438	0.005
Mfgr	0.729	1.000	1.000	1.000	1.000	0.955
Mfgr	0.865	0.998	0.967	0.995	0.927	0.119
	2 gpm	2 gpm	2 gpm	0.25 gpm	0.25 gpm	0.25 gpm
Meter Set	4 to 2 ft3	2 to 1 ft3	4 to 1 ft3	2 to 1 ft3	2 to 0.5 ft3	1 to 0.5 ft3
Mfgr	0.375	0.707	0.805	0.148	0.005	0.053
Mfgr	0.964	0.999	0.923	0.992	1.000	0.999
Mfgr	0.359	0.953	0.978	0.607	0.926	0.881

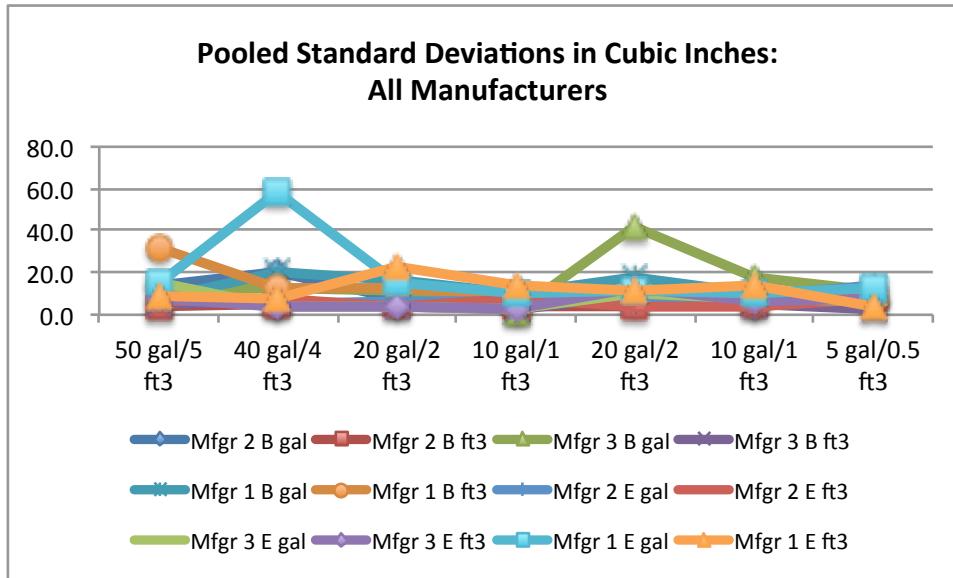
Below are the pooled standard deviations in cubic inches for the three manufacturers that performed three tests at each flow rate and each test draft size at the **end** of the survey.

Meter Set	50 gal 15 gpm	40 gal 2 gpm	20 gal 2 gpm	10 gal 2 gpm	20 gal 0.25 gpm	10 gal 0.25 gpm	5 gal 0.25 gpm
Mfgr	8.2	5.1	5.9	6.3	6.6	8.5	13.4
Mfgr	14.9	3.4	4.1	2.9	10.5	7.6	6.6
Mfgr	14.6	57.8	15.1	10.0	11.2	10.5	13.3
Meter Set	5 ft3 15 gpm	4 ft3 2 gpm	2 ft3 2 gpm	1 ft3 2 gpm	2 ft3 0.25 gpm	1 ft3 0.25 gpm	0.5 ft3 0.25 gpm
Mfgr	7.0	7.8	3.2	7.2	3.3	4.5	7.5
Mfgr	7.4	3.6	3.6	2.9	12.1	6.3	7.3
Mfgr	8.9	7.2	22.8	13.8	11.8	13.7	3.9

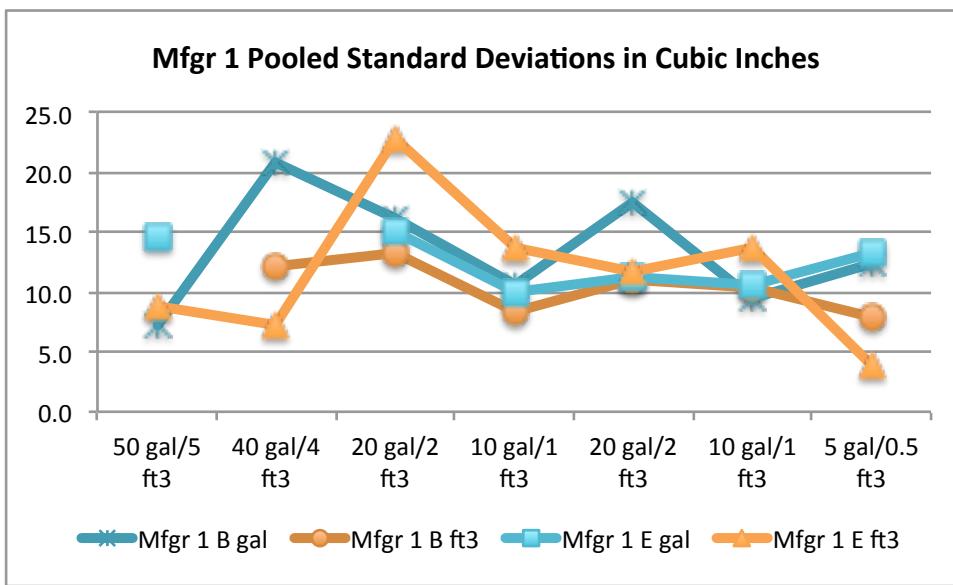
Below are the corresponding probabilities that the pooled standard deviations are statistically the same. There are 10 degrees of freedom for each pooled standard deviation. The cells that indicate that there is less than a 5 percent probability that the two pooled standard deviations are the same are shaded red. There are 7 out of 36 F-tests that indicate that the standard deviations that were compared are unlikely to be the same at a 95% confidence level. This indicates that there are significant differences in the repeatability of the meter groups for the same flow rates, but different sizes of test drafts.

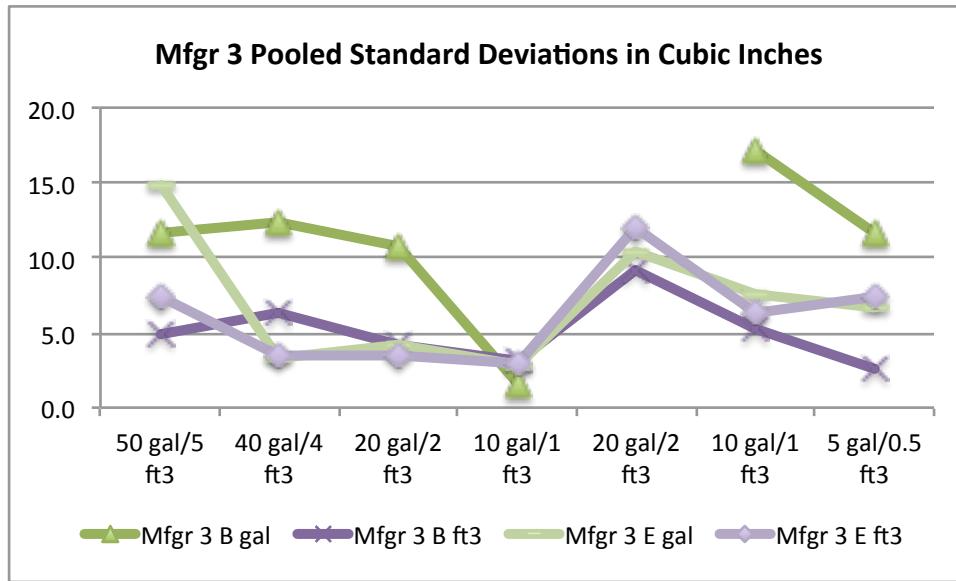
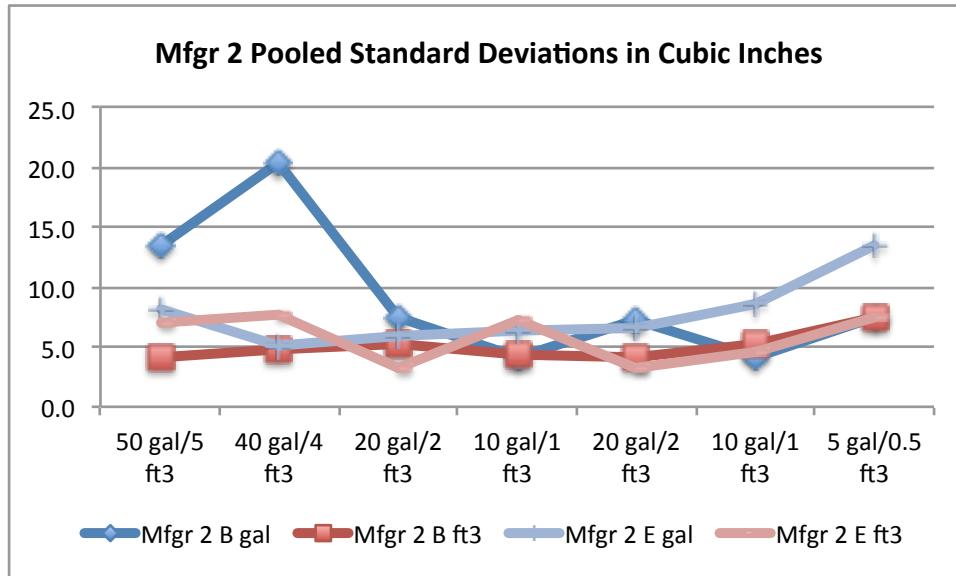
	2 gpm	2 gpm	2 gpm	0.25 gpm	0.25 gpm	0.25 gpm
Meter Set	40 to 20 gal	40 to 10 gal	20 to 10 gal	20 to 10 gal	20 to 5 gal	10 to 5 gal
Mfgr	0.256	0.181	0.398	0.122	0.001	0.024
Mfgr	0.186	0.767	0.946	0.918	0.976	0.728
Mfgr	1.000	1.000	0.964	0.616	0.230	0.151
	2 gpm	2 gpm	2 gpm	0.25 gpm	0.25 gpm	0.25 gpm
Meter Set	4 to 2 ft3	2 to 1 ft3	4 to 1 ft3	2 to 1 ft3	2 to 0.5 ft3	1 to 0.5 ft3
Mfgr	1.000	0.640	0.000	0.092	0.000	0.013
Mfgr	0.500	0.809	0.809	0.997	0.984	0.242
Mfgr	0.000	0.003	0.985	0.256	1.000	1.000

The charts below present the pooled standard deviations for the beginning and end tests for the three manufacturers. The first chart shows all of the pooled standard deviations for all three manufacturers. The chart shows that there are two “outliers” in the test results that compress the charts. These two outliers are omitted from the charts for the individual manufacturers so that the details are more easily observed.



The following charts show the pooled standard deviations for the three manufacturers for their beginning and end test results. One can see that pooled standard deviations, when expressed in volume units, do not show significant increases over the range of flow rates and sizes of test drafts, especially at the 0.25-gpm flow rate. The chart for manufacturer 2 shows a slight increase in the pooled standard deviation for the 5-gal test draft at 0.25 gpm. However, the charts for the other two manufacturers do not show any significant increase in the pooled standard deviation for the small test drafts at the flow rate of 0.25 gpm.





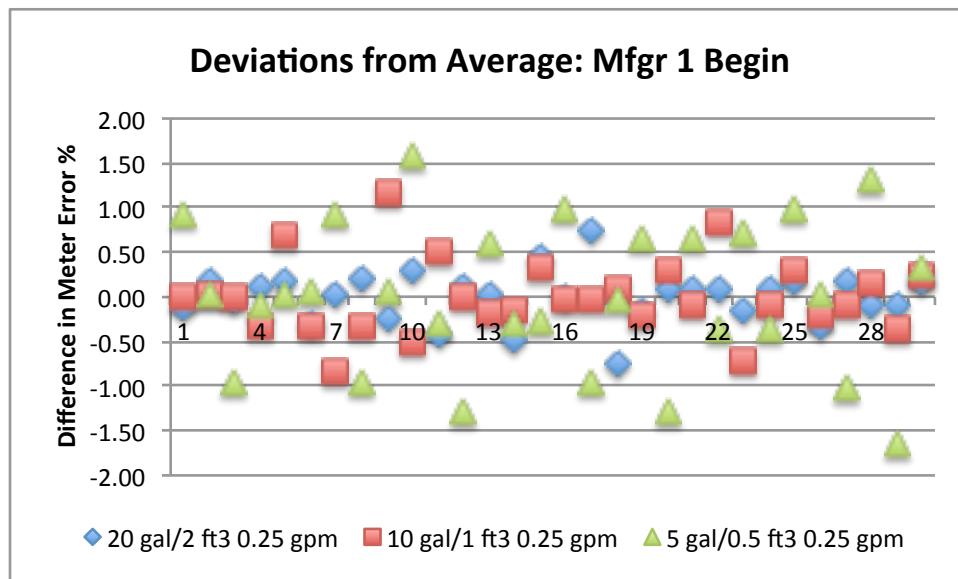
It is interesting to compare the variations for the meter error when expressed in volume units as shown above to the variation in test results when expressed in the percent meter error. The variations that are of greatest interest when the test results are expressed in percent meter error are for the minimum flow rate for the three different sizes of the test drafts. Hence, in the charts above, focus on the three plotted values at the far right. These three values are for the three test draft sizes at the minimum flow rate.

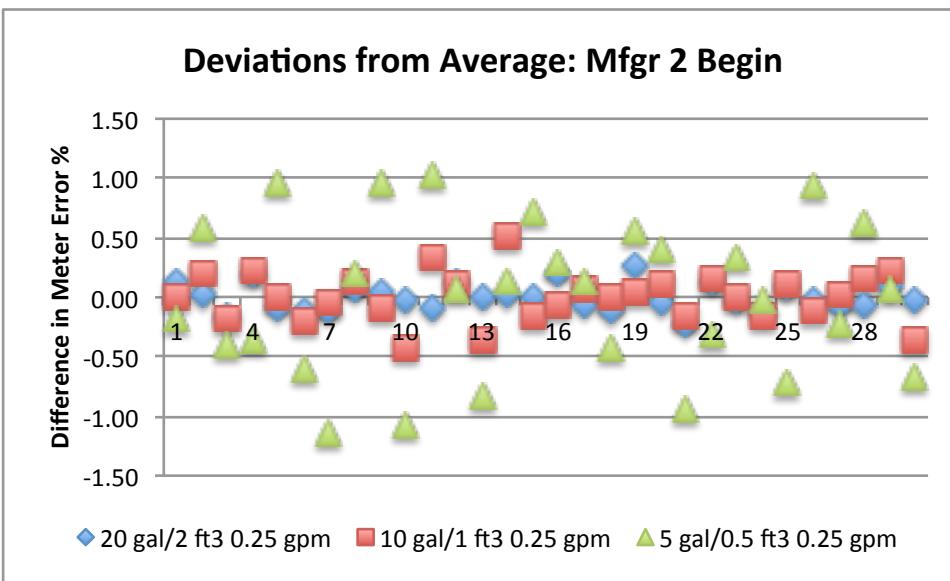
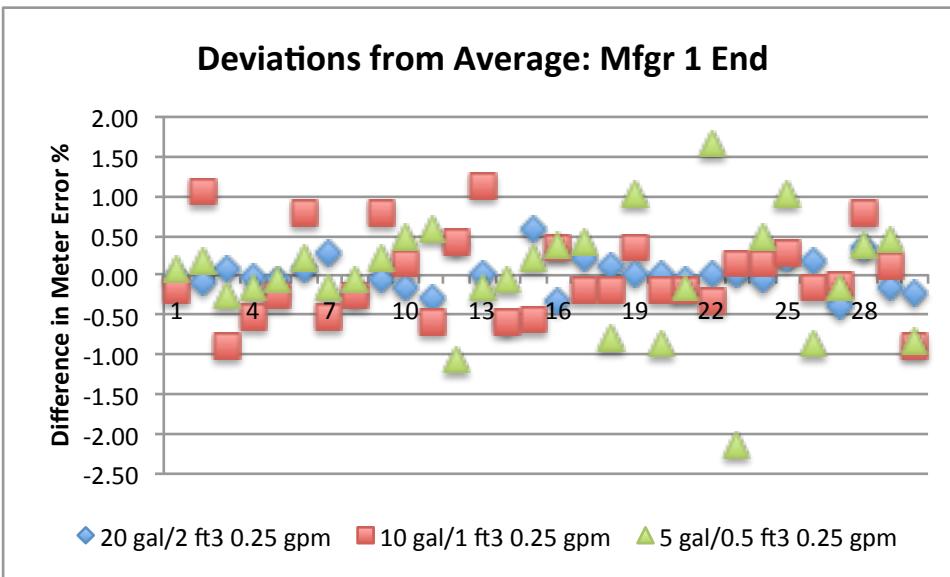
To illustrate the variations that exist when the accuracy test results are expressed in percent meter error for the different sizes of test drafts, the average error for each meter for each test draft size was subtracted from the three individual test results for each meter for each test draft size. These variations are analogous to the variations that are observed in the charts for the individual test results for each manufacturer for each meter. For each of the three manufacturers, one chart was prepared for the deviations from the average for

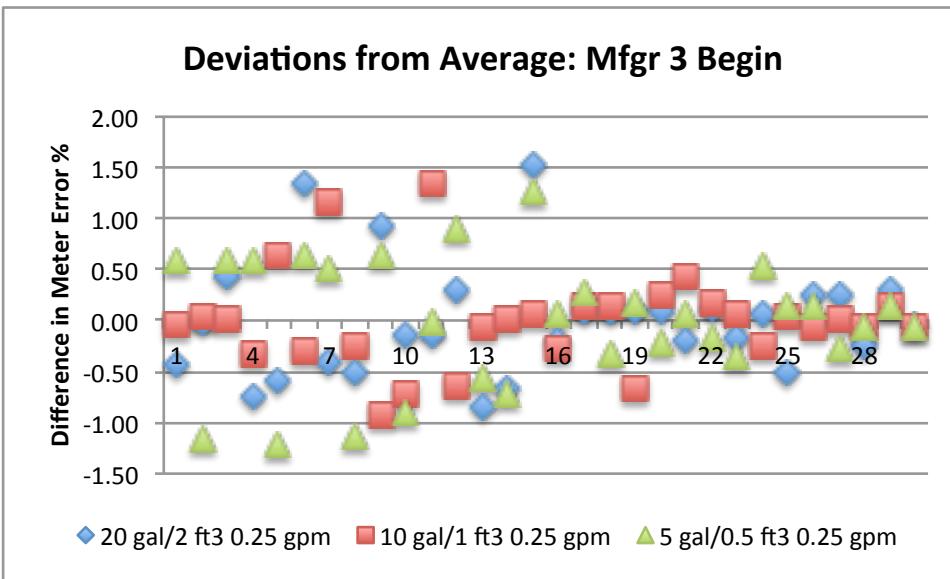
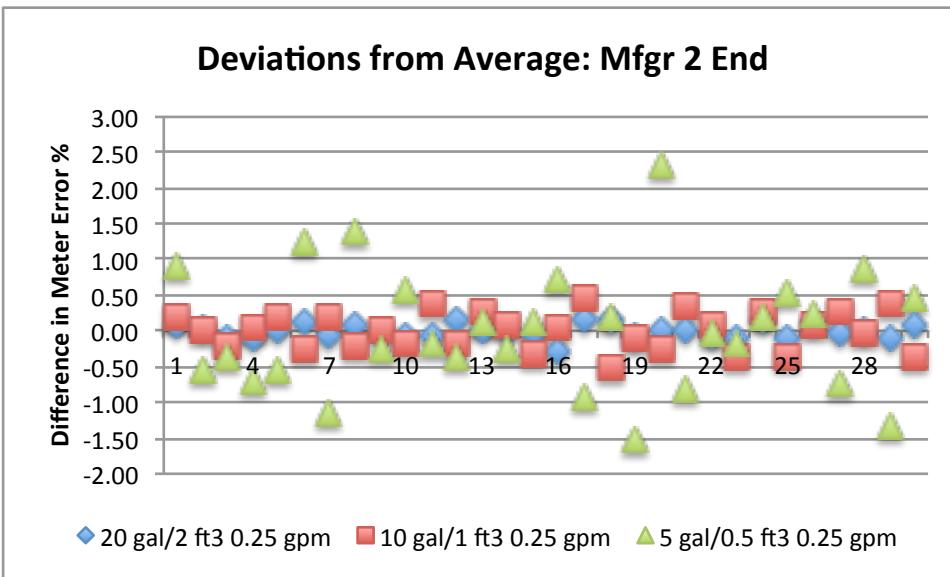
the beginning test results and another chart for the deviations from the average for the end test results. The two charts for each manufacturer follow. The charts illustrate how much larger the variations appear to be as test draft sizes get smaller when expressed as the percent meter error.

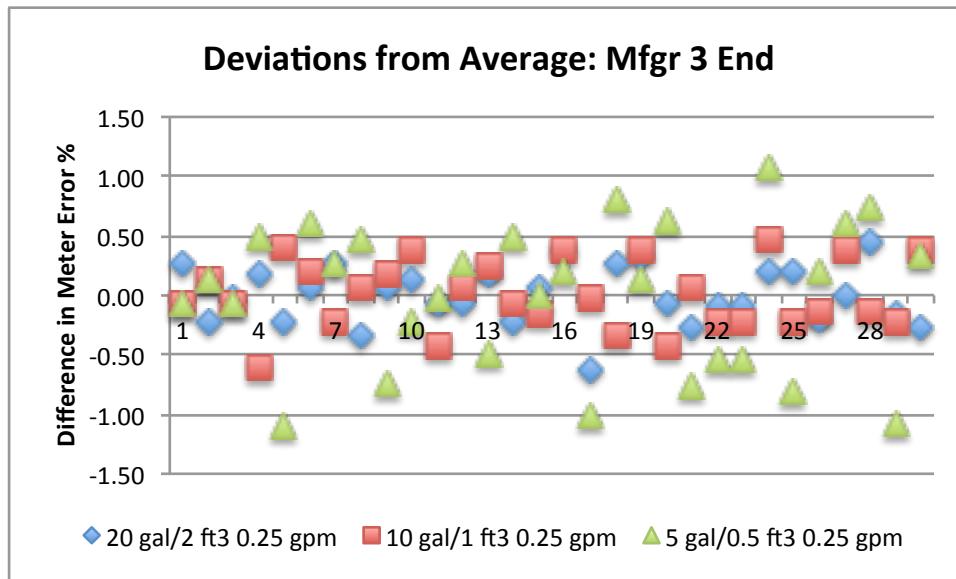
The key point of this discussion is that although the variations in test results when expressed in percent meter error generally appear to be much greater for the smaller test drafts, in fact, there is relatively little variation in the pooled standard deviations when expressed in cubic inches for the three sizes of test drafts at the minimum flow rate.

Another way of saying this is that the larger variations in test results when expressed in percent meter error is primarily due to the change in the size of the test draft as the test draft gets smaller for the minimum flow rate. This mathematical effect is generally much smaller for the higher flow rates because the sizes of the test drafts are generally much greater than the pooled standard deviations when expressed in cubic inches.









Below is a table that shows the pooled standard deviations in cubic inches for the DMS tests at the beginning and end of the survey. The pooled standard deviations at the **beginning** of the survey were pooled for the meters from each manufacturer (as noted by the letter B and M1, M2, M3 and M4 in the left column). The charts showing the pooled standard deviations at the **end** of the survey were pooled for the meters that were in each group of meters (designated by the letter E and the group letter A, B, C and D in the left column).

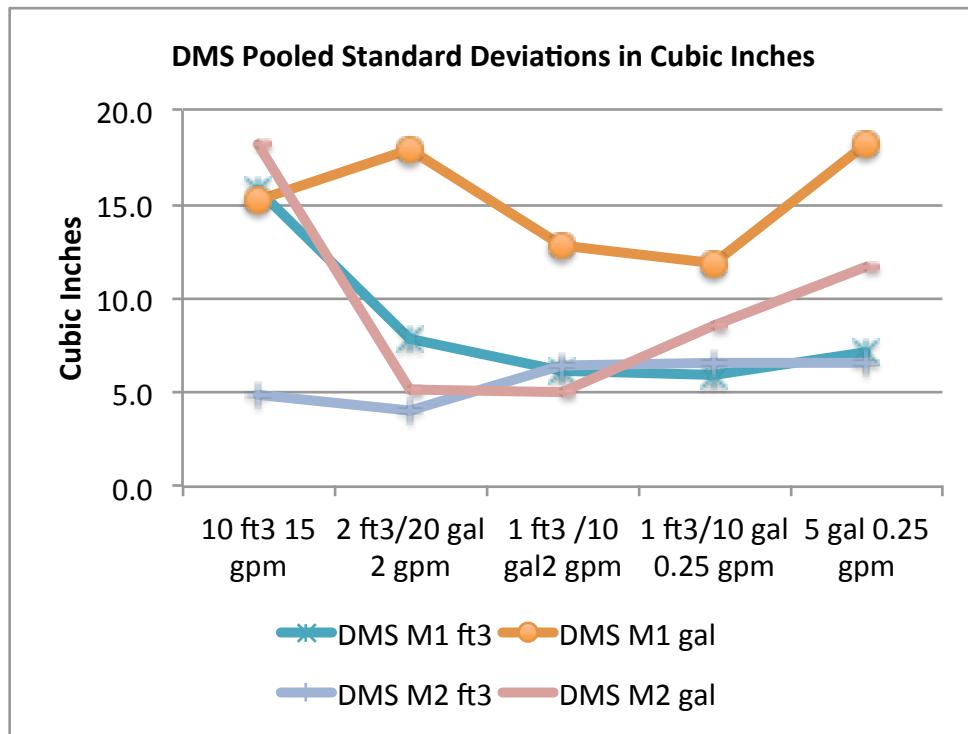
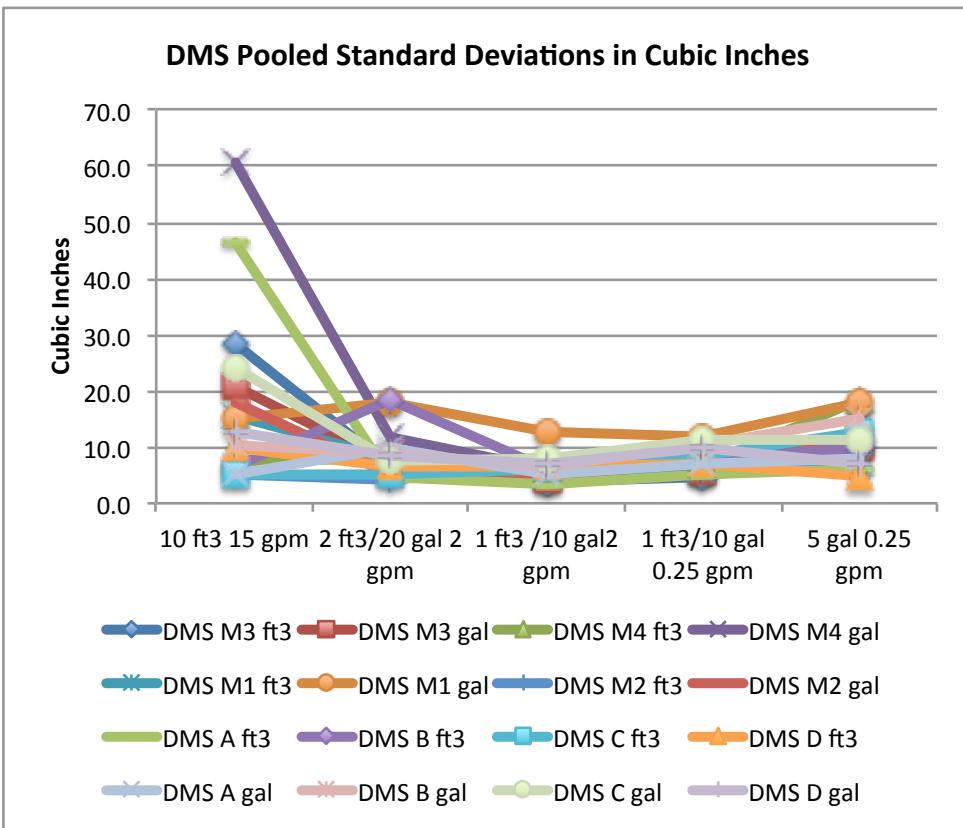
DMS Results	10 ft ³ at 15 gpm	2 ft ³ /20 gal at 2 gpm	1 ft ³ /10 gal at 2 gpm	1 ft ³ /10 gal at 0.25 gpm	5 gal at 0.25 gpm
DMS B M3 ft ³	28.3	6.5	3.8	4.8	9.7
DMS B M3 gal	21.0	6.8	4.0	5.5	9.7
DMS B M4 ft ³	7.6	7.8	7.8	6.4	18.3
DMS B M4 gal	60.7	11.6	5.9	6.2	10.9
DMS B M1 ft ³	15.8	7.9	6.2	5.9	7.1
DMS B M1 gal	15.2	17.9	12.9	11.9	18.2
DMS B M2 ft ³	4.9	4.0	6.5	6.5	6.5
DMS B M2 gal	18.2	5.1	5.0	8.6	11.7
DMS E A ft ³	46.7	4.6	3.4	5.2	6.2
DMS E B ft ³	6.6	18.6	5.9	7.9	9.7
DMS E C ft ³	5.1	5.2	6.0	8.5	12.9
DMS E D ft ³	9.8	6.5	6.4	7.1	4.8
DMS E A gal	5.3	10.1	5.2	7.1	7.9
DMS E B gal	10.4	8.9	6.5	10.5	15.0
DMS E C gal	24.1	7.6	7.8	11.1	11.4
DMS E D gal	12.7	8.4	7.0	10.0	7.1

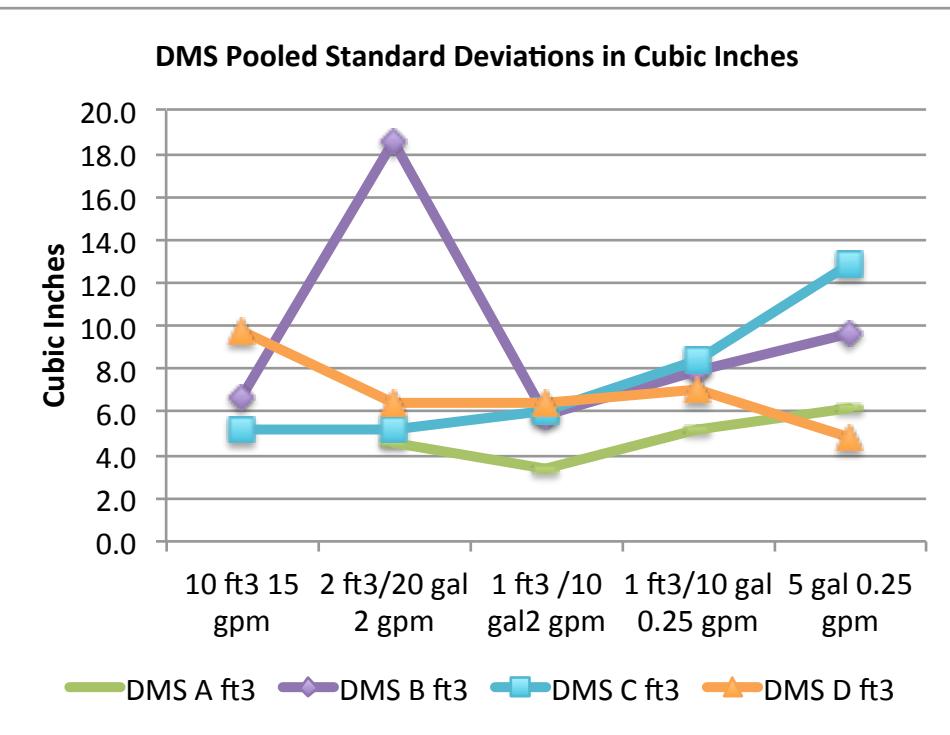
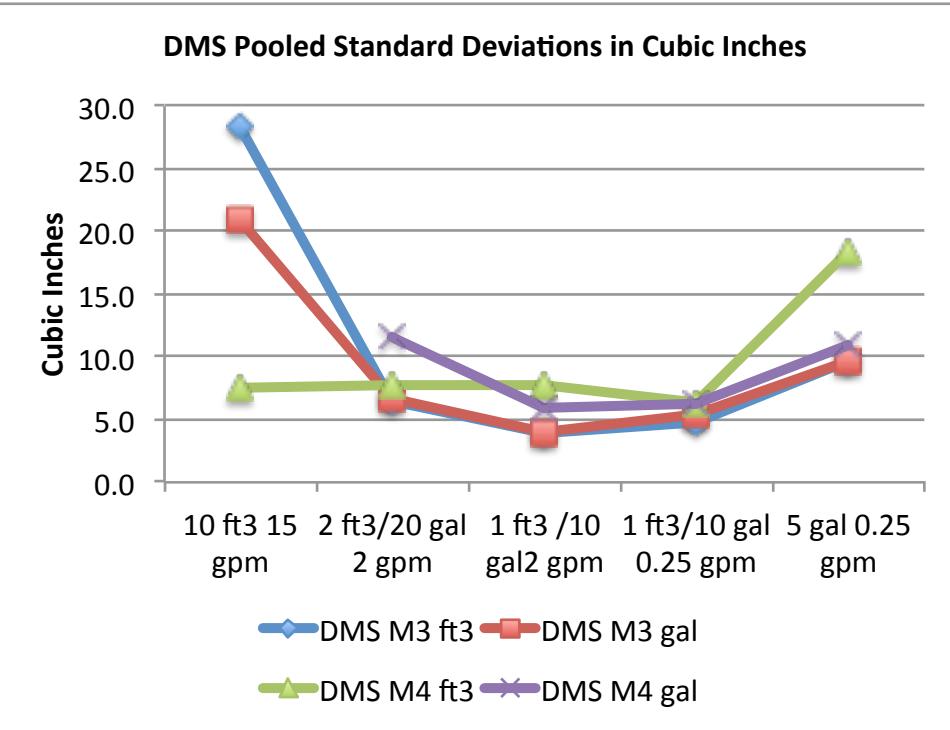
The probabilities that the pooled standard deviations for the DMS results are likely to be the same are shown in the table to the right. The comparisons are for the same flow rates, but for the different sizes of test drafts at each flow rate. The cells shaded in red (six results out of 32) indicate where there is less than a 5% statistical probability that the pooled standard deviations are the same.

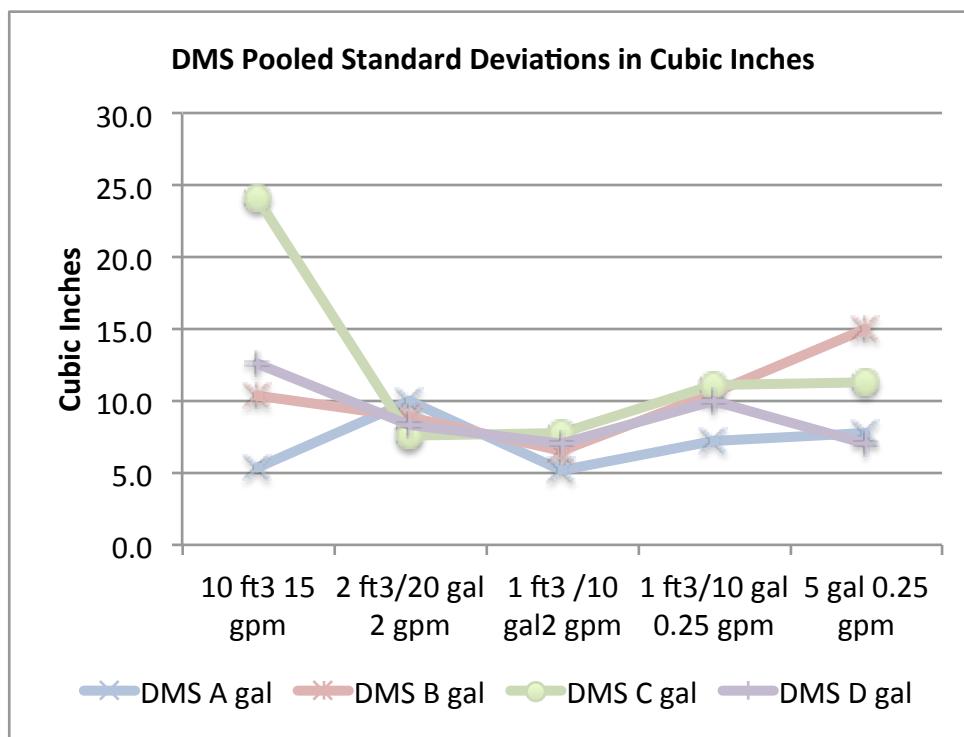
The pooled standard deviations for the DMS tests at the beginning and end of the survey are shown on the charts below. Again, the first chart shows the pooled standard deviations for all of the tests. There are two "outliers" for the tests at 15 gpm for the 10-ft³ test draft. These outliers were omitted from the other DMS charts to better show the pooled standard deviations with respect to each flow rate and test draft.

The pooled standard deviations at the beginning of the survey were pooled for the meters from each manufacturer (as noted by M1, M2, M3 and M4 in the legend) and shown separately for meters indicating in gallons and cubic feet. The charts showing the pooled standard deviations at the end of the survey were pooled for the meters that were in each group of meters (designated by an A, B, C and D) as tested by the county laboratories. One can see that the pooled standard deviations for the 5-gal test draft at the minimum flow rate of 0.25 gpm tended to be larger than the standard deviations for the 10-gal test draft at the minimum flow rate. It is interesting that, in general, the results for the manufacturers did not exhibit this characteristic for the 5-gal or 0.5 ft³ test drafts at the minimum flow rate. The trend to larger standard deviations for the DMS results for the smallest sizes of test drafts implies that something in the DMS test facility or in the test procedure is contributing to the increased standard deviations for the smallest test drafts.

	2 gpm	0.25 gpm
DMS B M1 ft3	0.778	0.287
DMS B M1 gal	0.846	0.098
DMS B M2 ft3	0.076	0.494
DMS B M2 gal	0.523	0.175
DMS B M3 ft3	0.944	0.018
DMS B M3 gal	0.944	0.044
DMS B M4 ft3	0.512	0.001
DMS B M4 gal	0.978	0.042
DMS E A ft3	0.821	0.308
DMS E A gal	0.977	0.381
DMS E B ft3	0.999	0.268
DMS E B gal	0.827	0.138
DMS E C ft3	0.330	0.101
DMS E C gal	0.463	0.465
DMS E D ft3	0.519	0.878
DMS E D gal	0.712	0.859







Individual Test Results for Each Meter

The repeatability of individual test results varied from laboratory to laboratory. Additionally, one can see how the results from some labs are offset from others. Two crucial questions are, “Are the apparent offsets from laboratory to laboratory statistically significant (that is, statistically detectable)? Are the offsets of practical significance relative to the tolerances for the meters?” To address these questions, the test results are presented in several types of charts.

Counties 35 and 50 each tested on group of meters indicating in gallons and a second group of meters indicating in cubic feet. County 27 did not conduct any tests at 2 gpm. The test facilities at the following laboratories did not permit testing of all five meters in a single series: 6, 25, 27, 34, 53, 57, 93 and 94. Laboratory 27 tested four meters in each group of meters that were tested.

Below are charts for the individual test results for each meter for each flow rate. The first chart for a flow rate shows the individual test result in the sequence in which the meters were tested. The second chart presents the individual test results with the tolerance limits shown for the flow rate. The first graph shows the individual test errors as determined by the laboratories. The y-axis is scaled to provide more vertical separation in the results. The second graph shows the individual meter errors with the tolerance limits shown for each flow rate to provide the perspective of the variations (for each laboratory and between laboratories) relative to the tolerance limits.

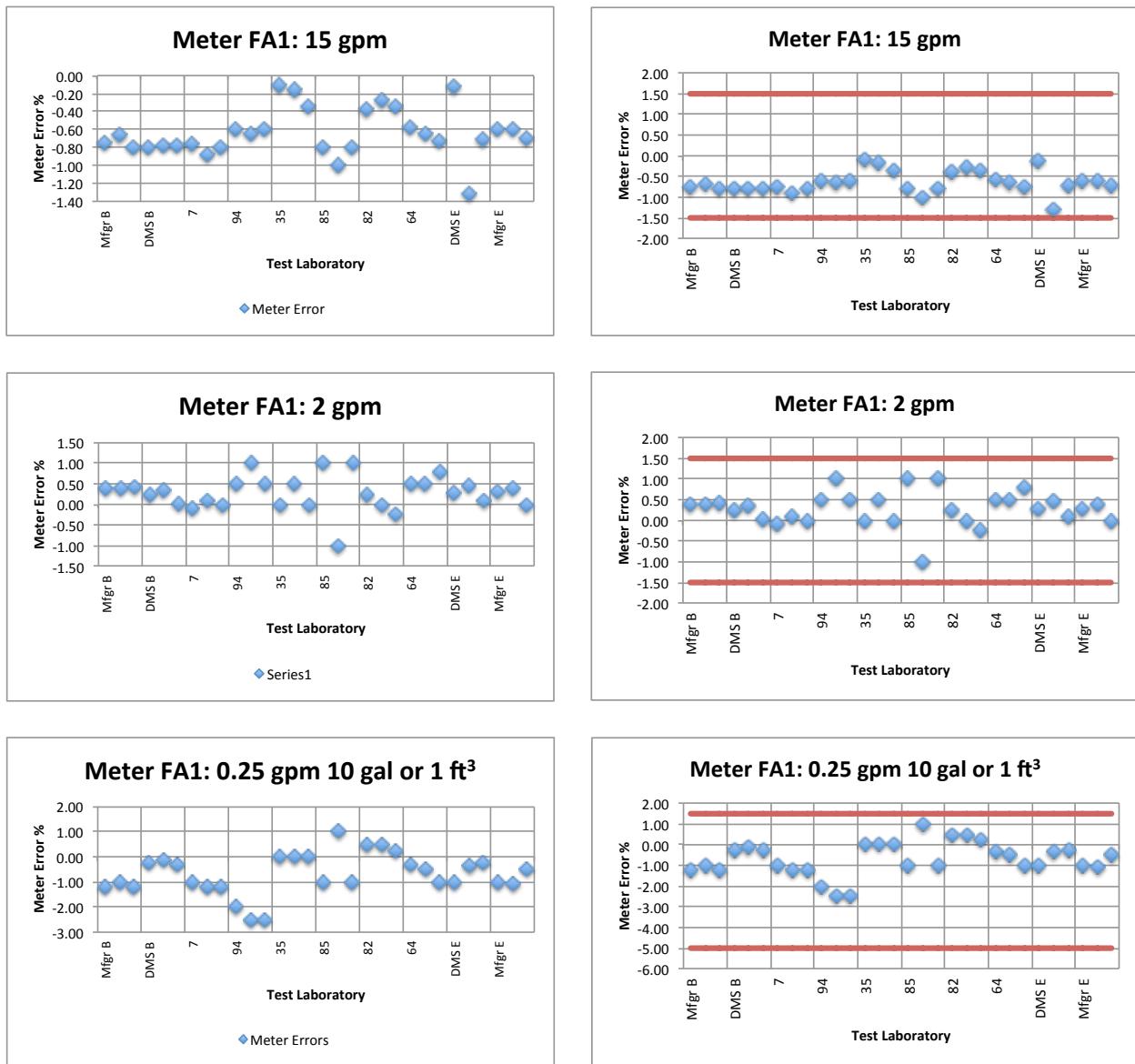
Below is a list of comments regarding some of the graphs of the individual test errors. Additional comments are provided in the section that analyzes the results for the individual counties.

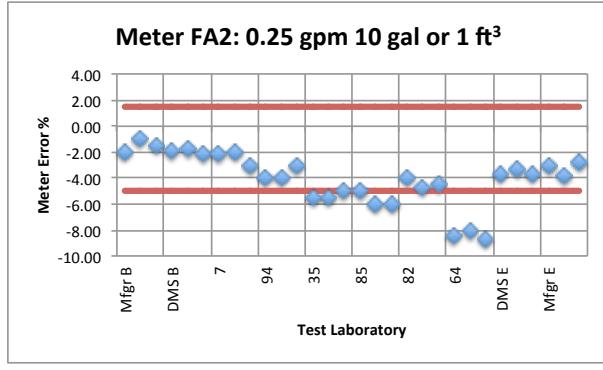
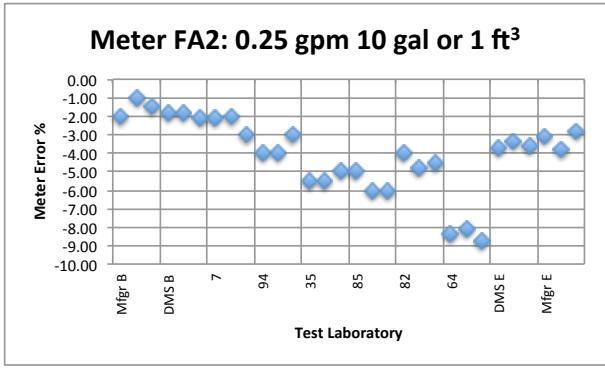
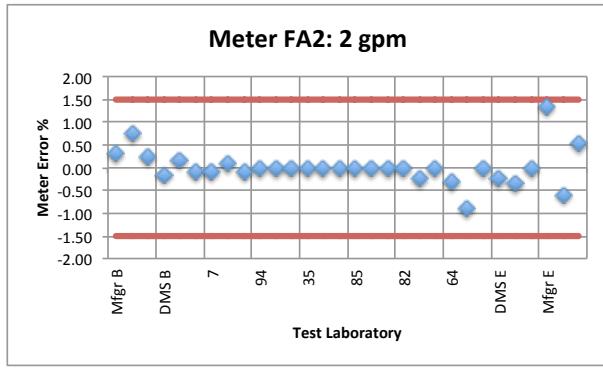
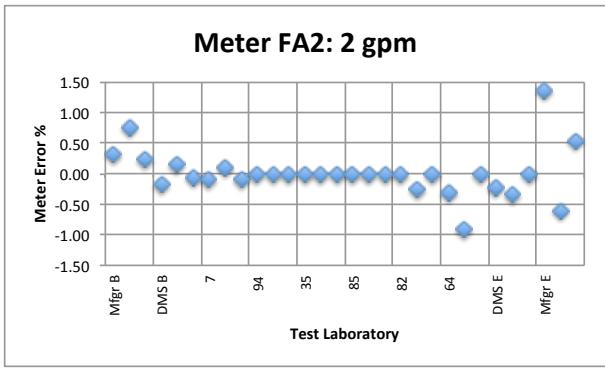
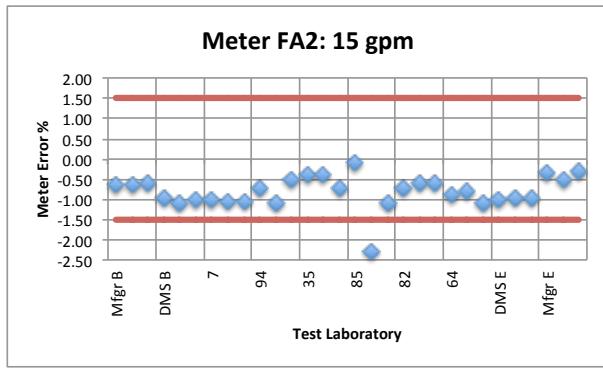
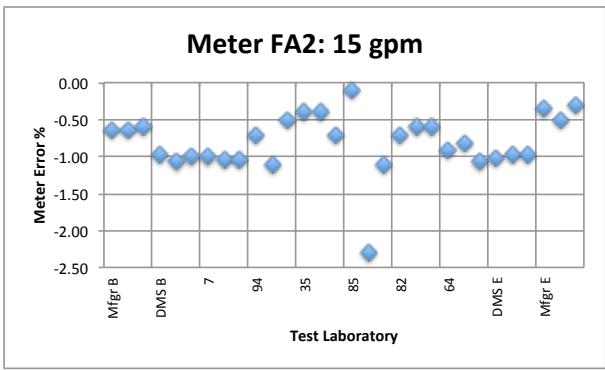
Meter	Flow Rate gpm	Comments
FA1	15	There are offsets for some laboratories, but all of the results are within tolerance.
FA1	0.25	The distribution of errors is a bit unusual.
FA2	2	Three consecutive labs recorded zero error at this flow rate. While this is unusual, it is not a problem.
FA2	0.25	The accuracy of the meter appears to have changed at this flow rate.
FA3	15	This is an unusual sequence of test results, but all are within tolerance.
FA5	0.25	The initial DMS test results are offset.
FB1	15	There are offsets among the labs.
FB1	0.25	The results for two counties show large negative errors; however, these results may be due to the meter rather than the county test facilities.
FB2	2 and 0.25	There is a peculiar distribution to the test results.
FB3	0.25	The accuracy of the meter may have changed at this flow rate.
FB4	15	There may be an upward trend in the test results, but the change is small.
FC3	15	Most of the counties have an offset to the manufacturer and DMS.
FC4	15	Most of the counties are offset from the manufacturer and DMS, but the results are within tolerance.
FC5	15 and 2	The manufacturer has some large variations in the test results.
FD2	15	Two counties are offset from the others, but the results are within tolerance.
FD2	15 and 2	Some counties had some significant variations in the test results.
FD4	15	Three lab results are offset from the others.
FD4	0.25	The accuracy of the meter appears to have changed at this flow rate.
FD5	All	There are some significant variations in the test results for some labs.
GA1	2 and 0.25	The accuracy of the meter appears to have changed at these flow rates.
GA2	0.25	The accuracy of the meter may have changed at this flow rate.
GA5	All	Some labs had significant variations in the test results.
GB2	0.25	The accuracy of the meter may have changed at this flow rate.
GB4	15	The county results are offset from the manufacturer and DMS, but the results are within tolerance.
GB5	0.25	The accuracy of the meter appears to have changed at this flow rate.
GC1	15	The county results are offset from the manufacturer and DMS, but the results are within tolerance.

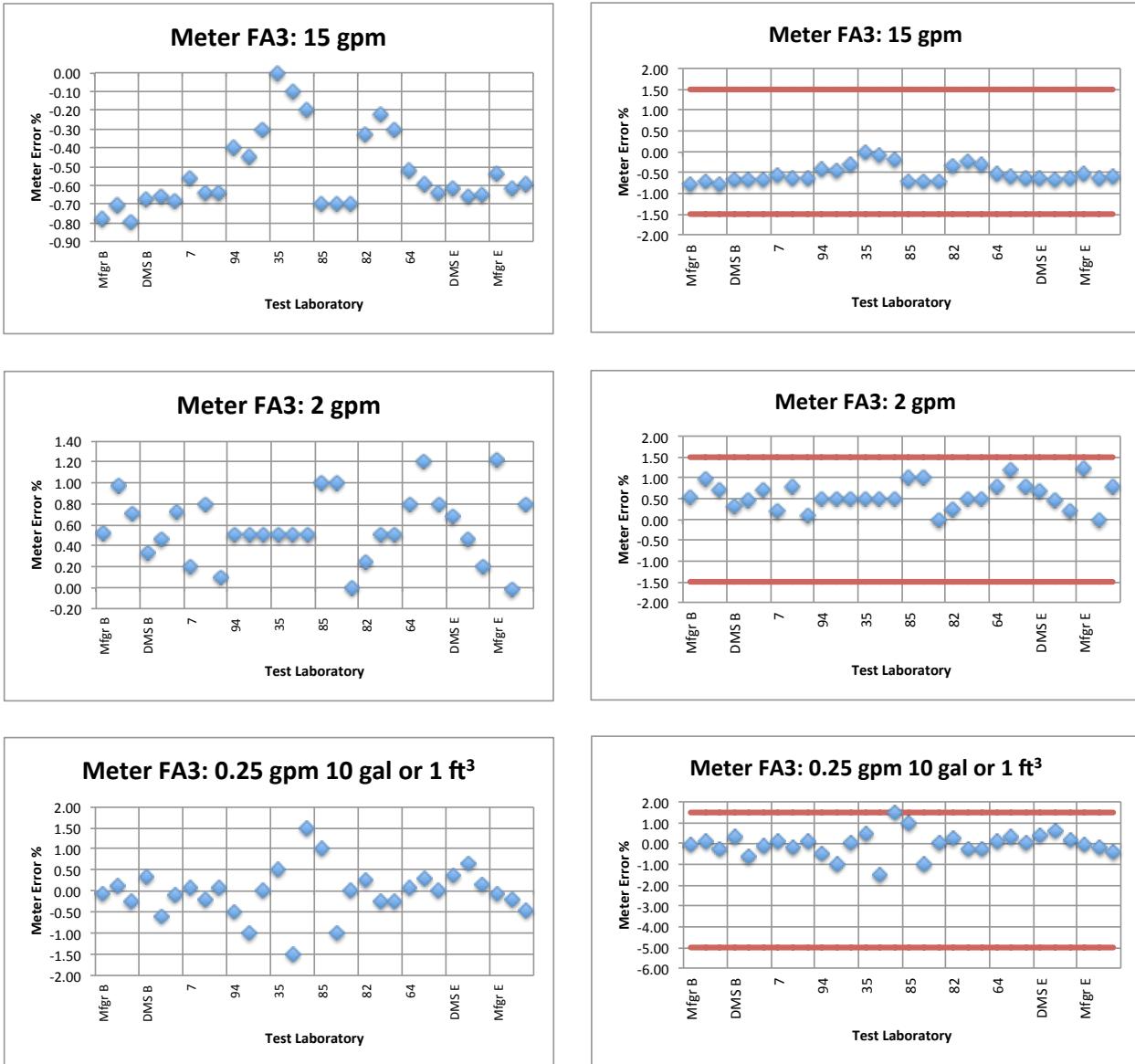
Meter	Flow Rate gpm	Comments
GC2	15	The DMS results had more variations than the other labs.
GC2	0.25	There are significant variations in the test results for the 5-gal test.
GC3	15	The results of the other labs are offset from the DMS results, but the results are within tolerance.
GC4	15	The county results are offset from the manufacturer and DMS, but the results are within tolerance.
GD1	0.25	There are some large variations in the test results for some labs.
GD2	All	There are some unusual offsets and variations in the test results.
GD3	All	There are some unusual offsets and variations in the test results.
GD4	0.25	The accuracy of the meter may have changed at this flow rate.

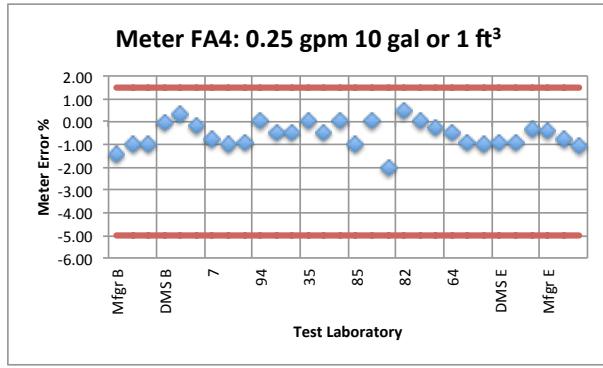
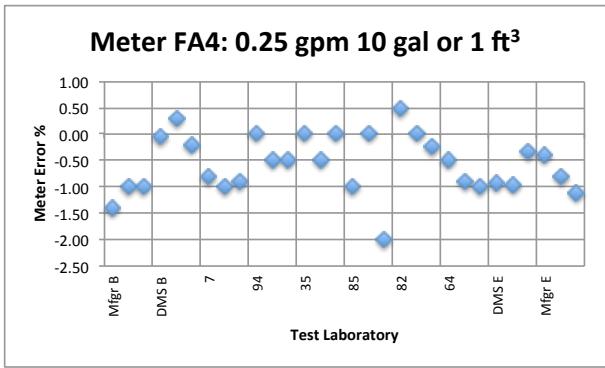
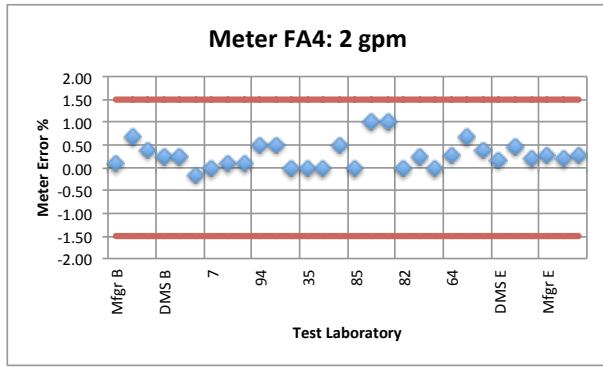
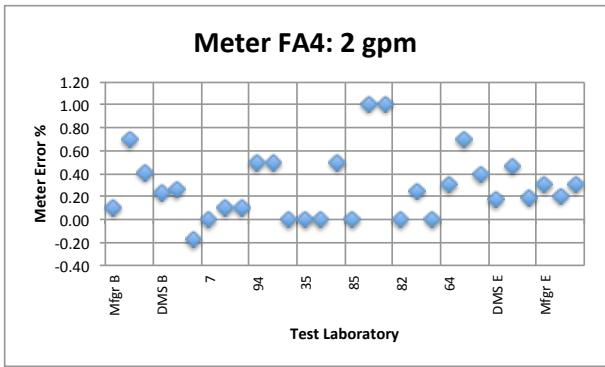
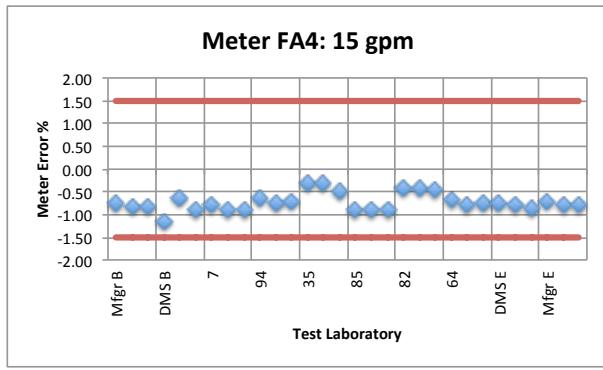
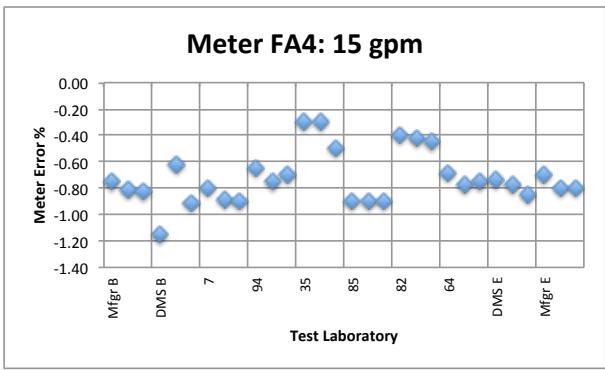
A change in meter accuracy over the length of the study can be detected by any upward or downward trends in the test results.

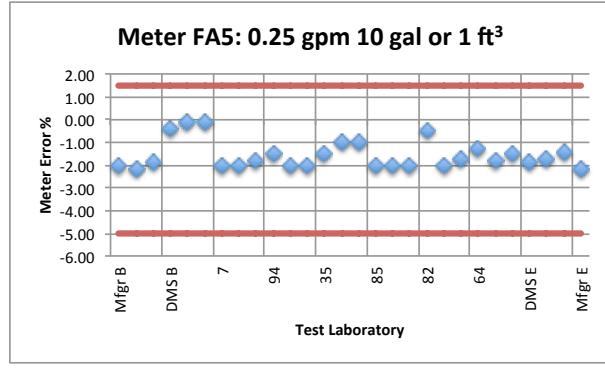
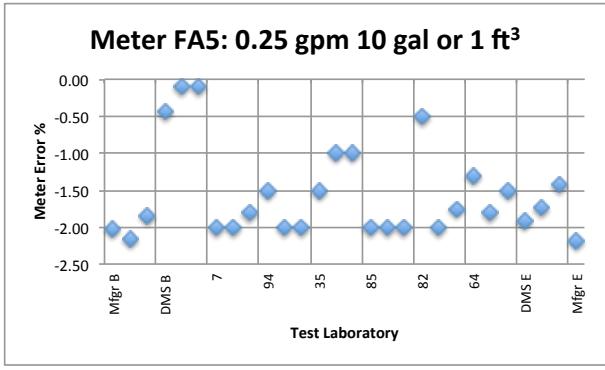
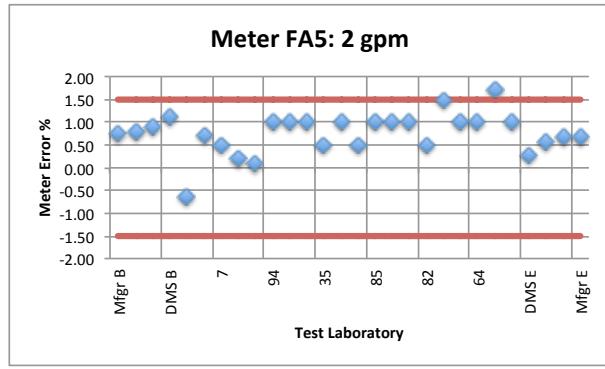
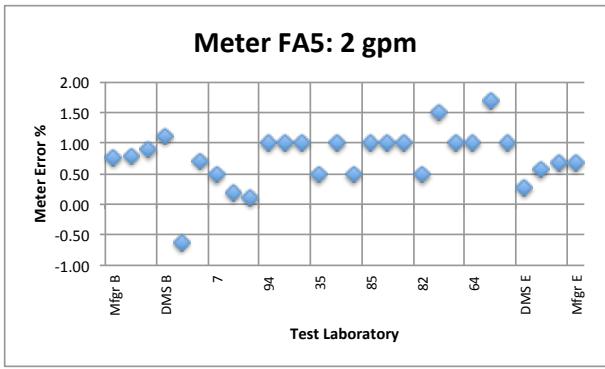
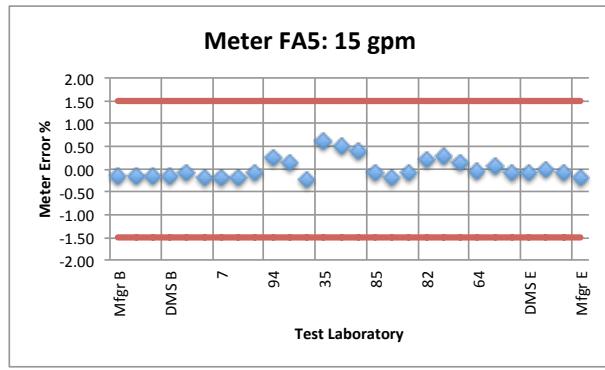
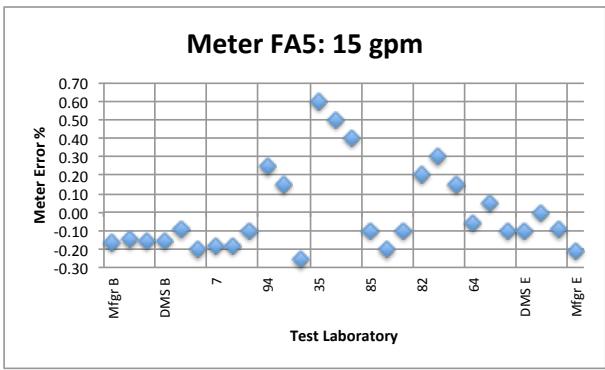
An overall evaluation of the test results can be obtained by examining the test results for each meter as tested in sequence by each laboratory. For meters indicating in gallons, the results for the different test draft sizes of 10 gal and 5 gal are shown on separate charts. Each manufacturer tested its own meters at the beginning and the end of the survey. The manufacturer's results at the beginning and end of the survey are identified as Mfgr B and Mfgr E, respectively. The same codes are used for all manufacturers, but each manufacturer can identify its meters by the meter identification in the titles of the charts. The California Division of Measurement Standards tested all of the meters at the beginning and end of the survey. The DMS results at the beginning and end of the survey (i.e., before and after the county tests) are identified as DMS B and DMS E, respectively. The codes for the counties that tested the specific meter are shown in the labels for the X-axis.

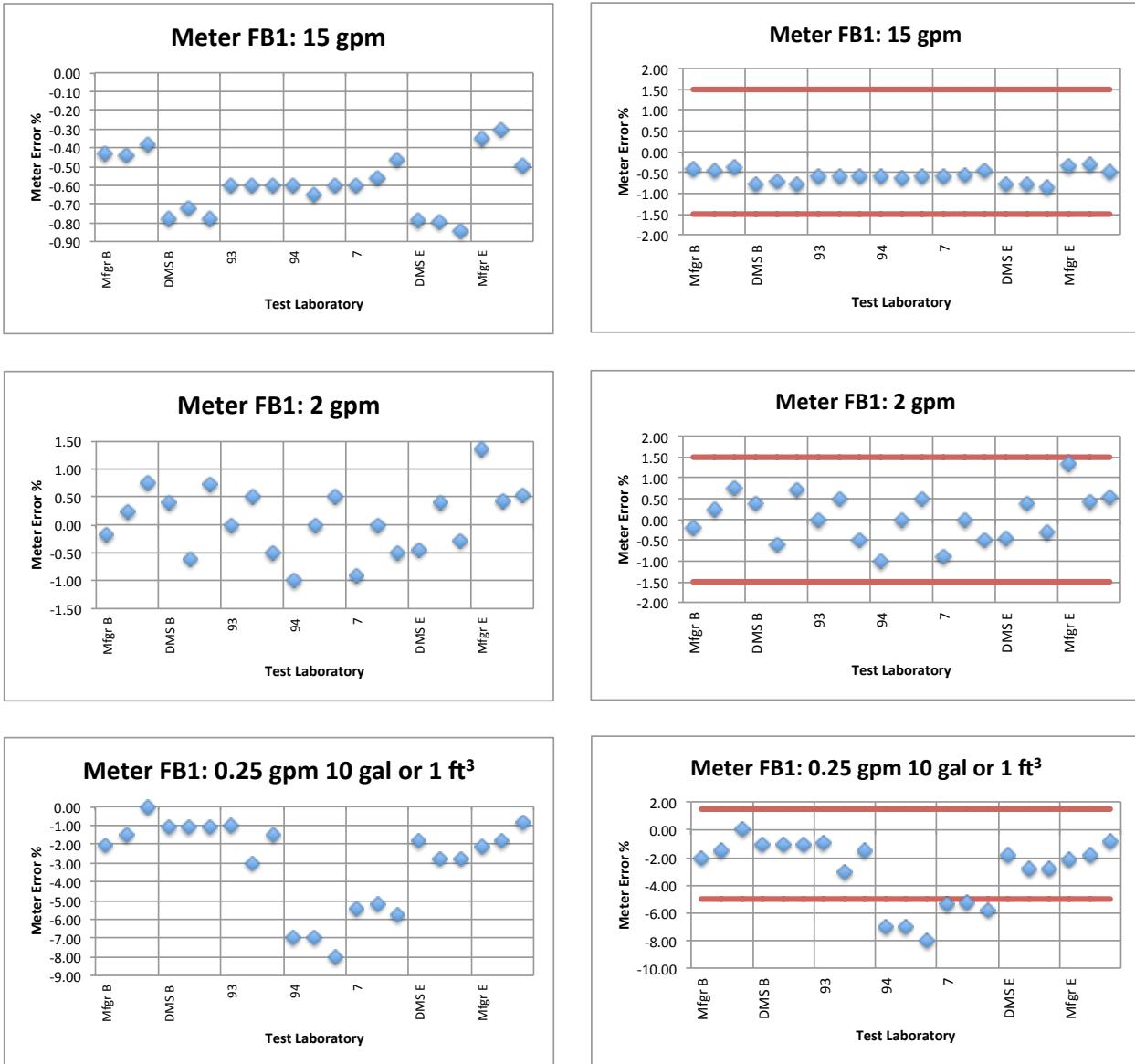


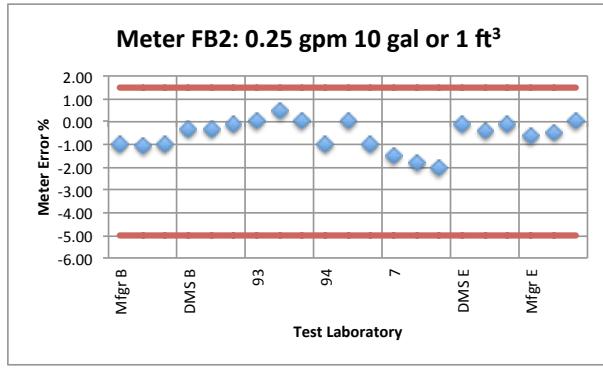
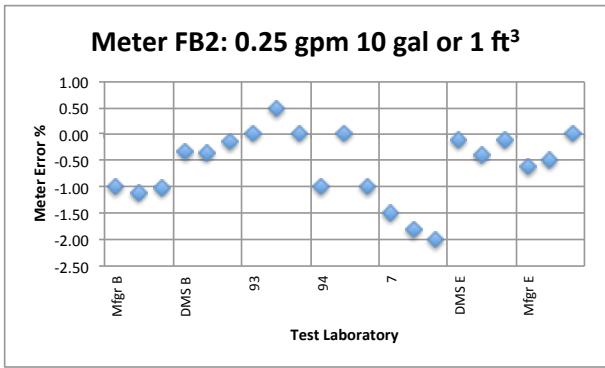
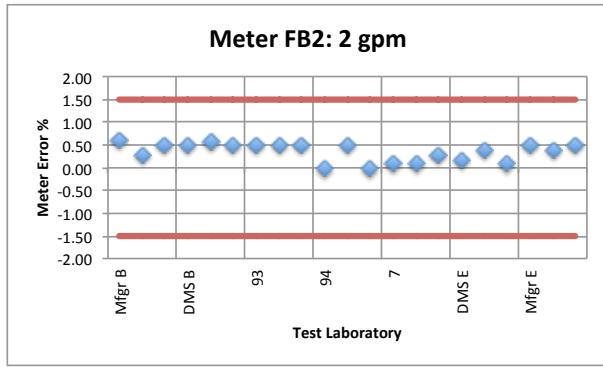
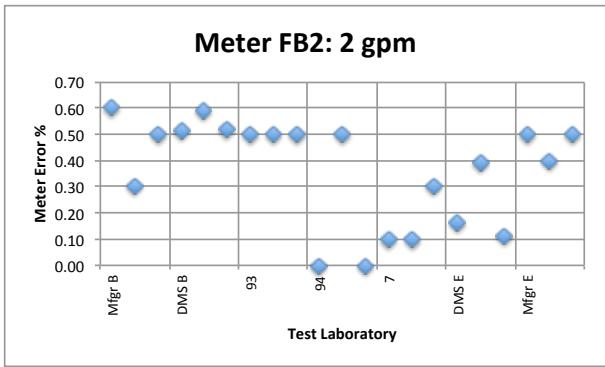
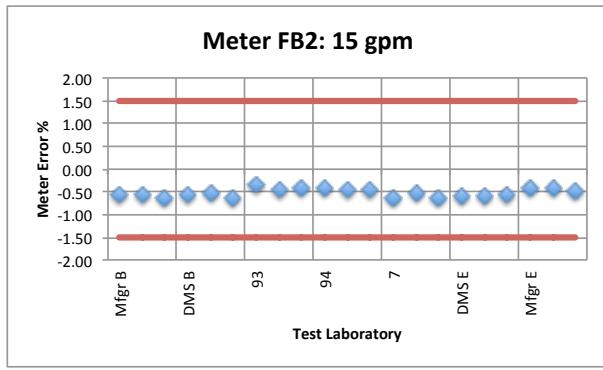
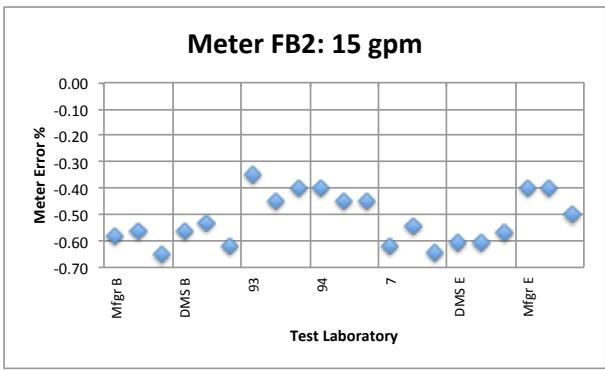


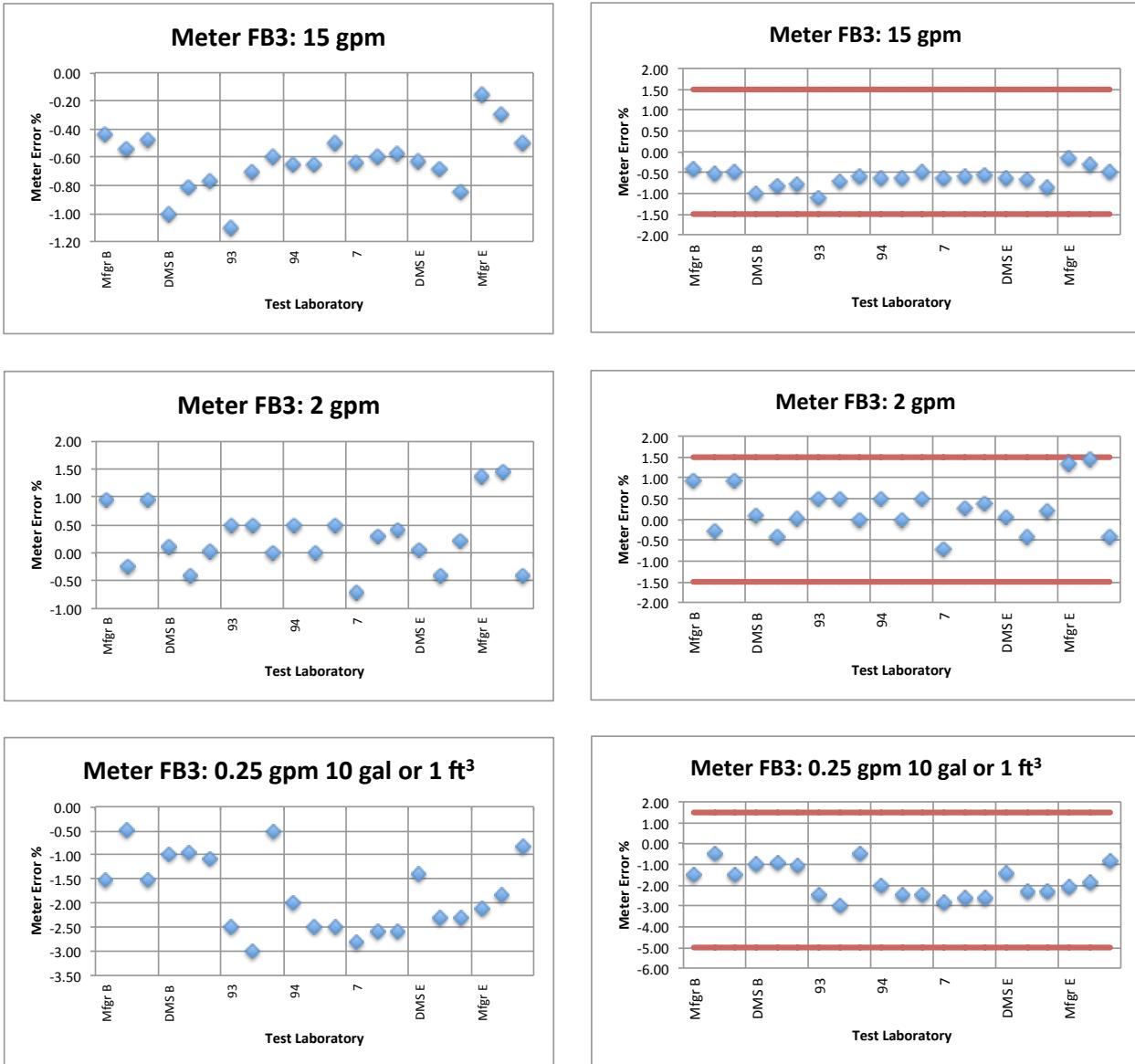


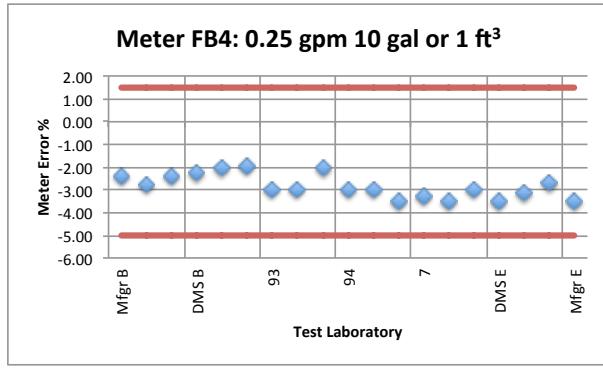
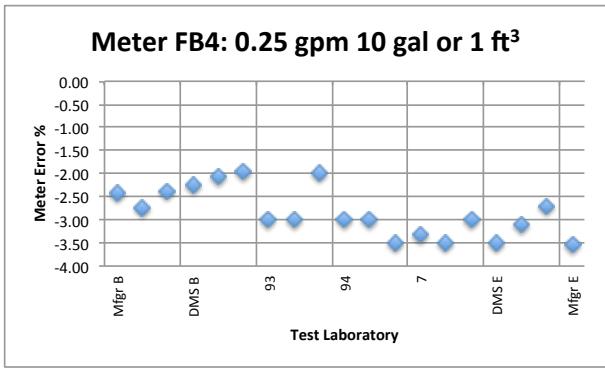
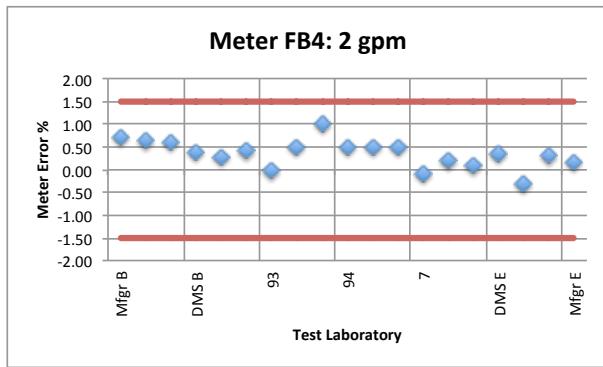
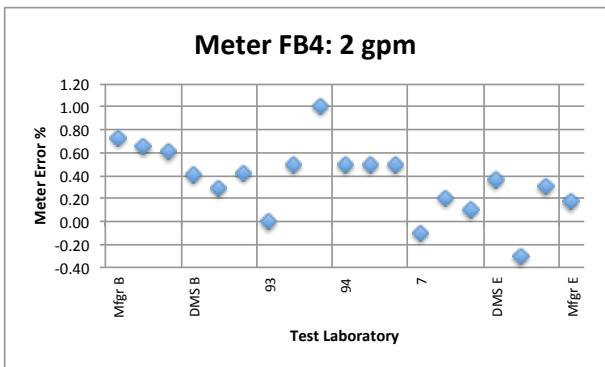
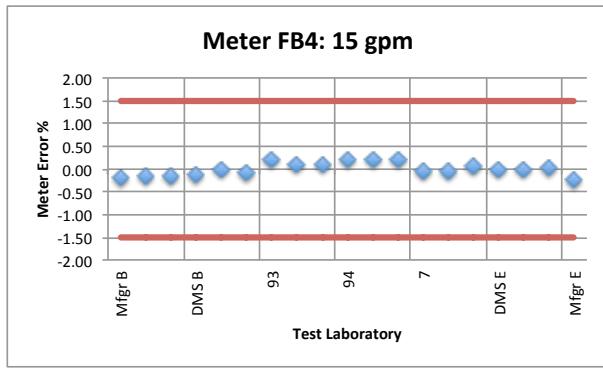
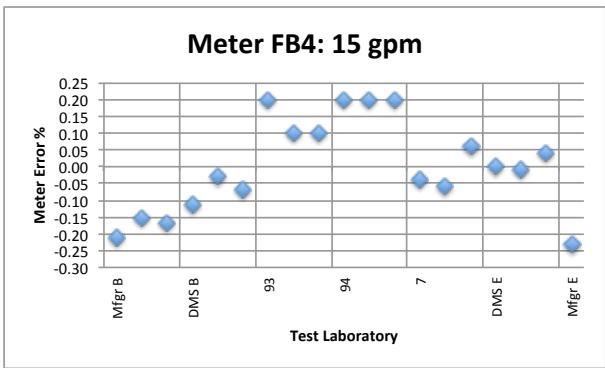


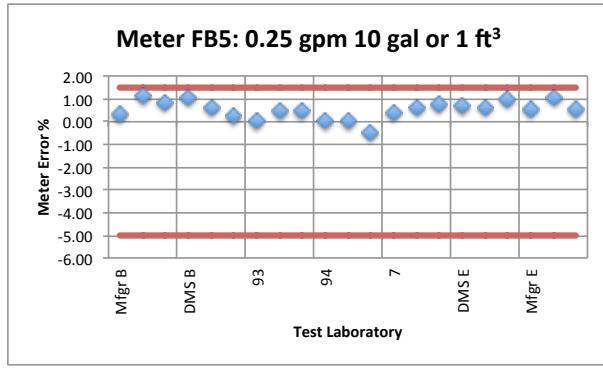
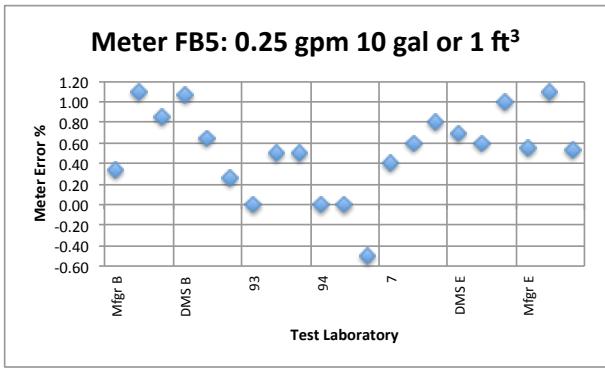
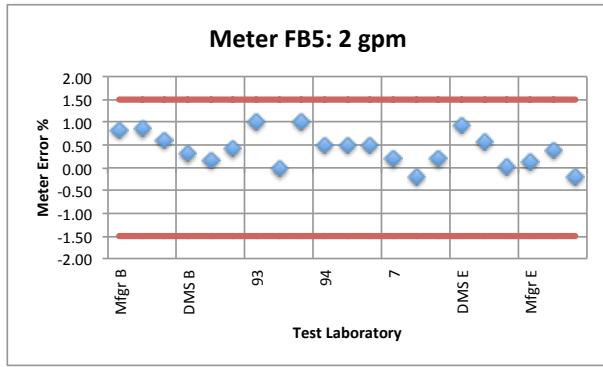
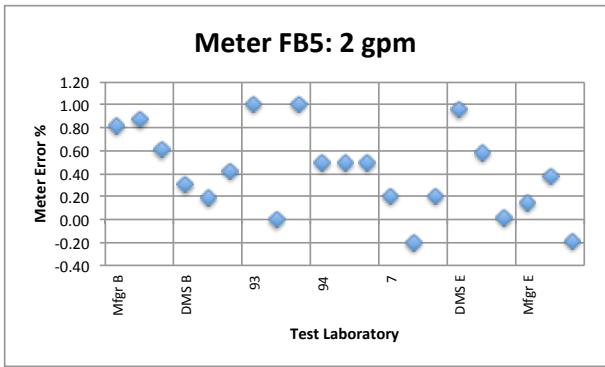
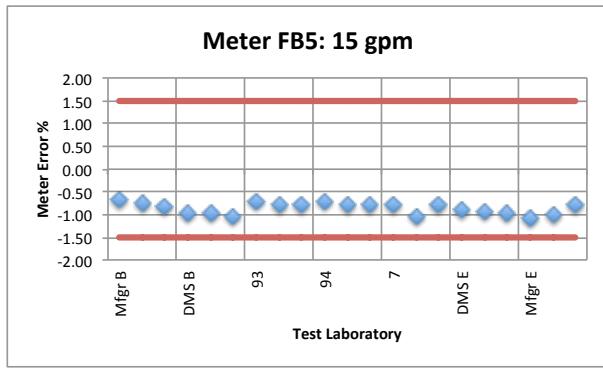
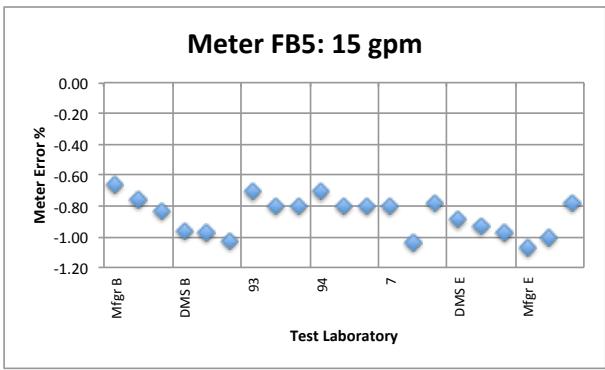


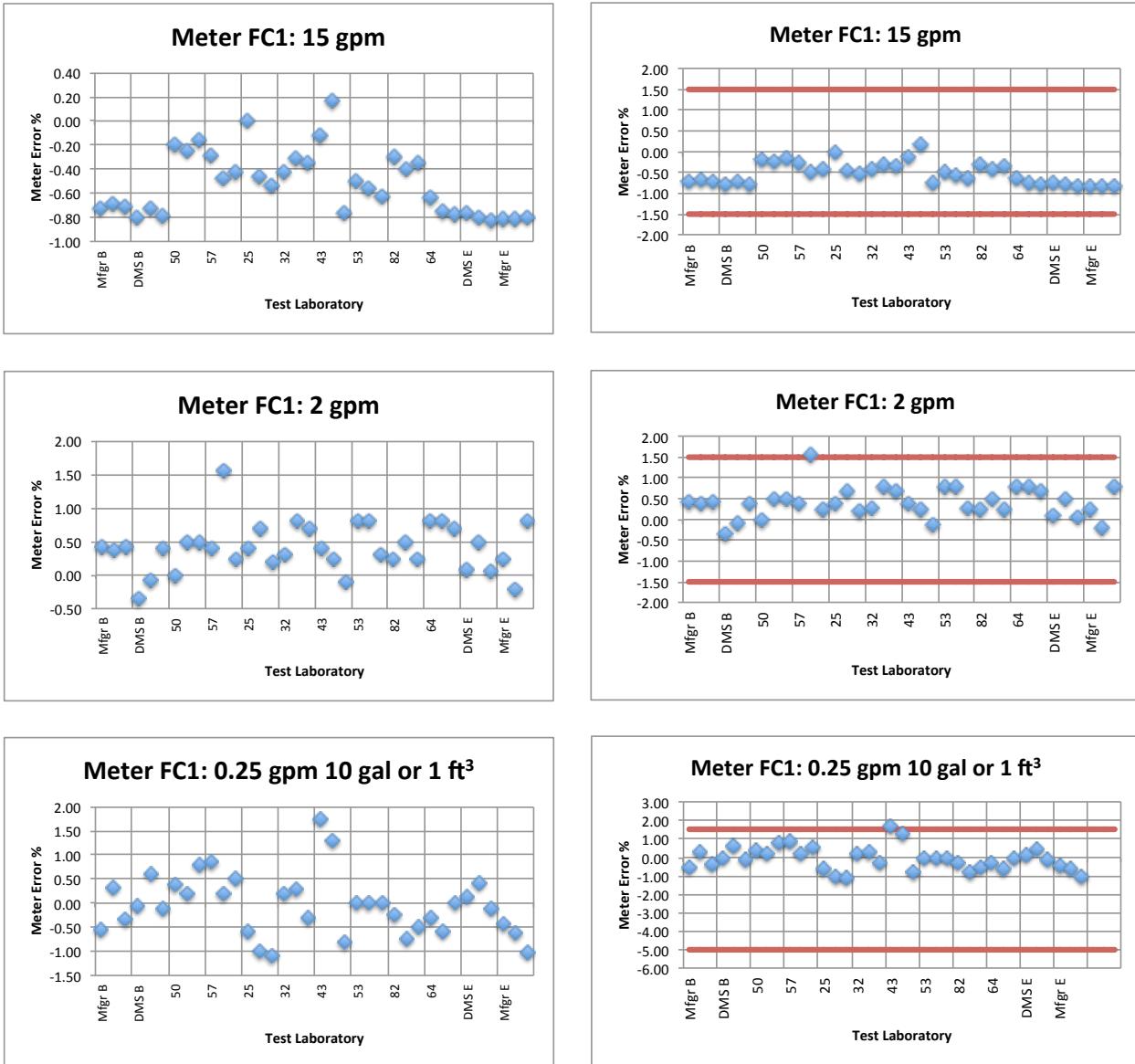


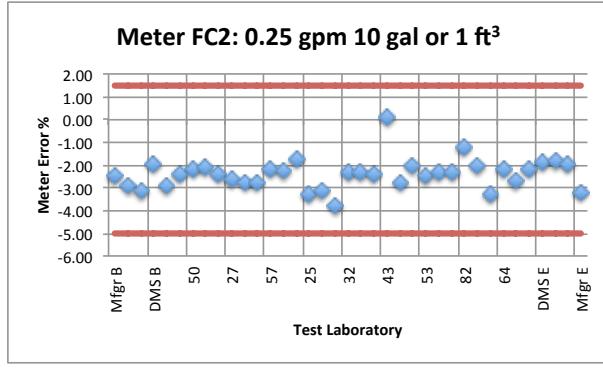
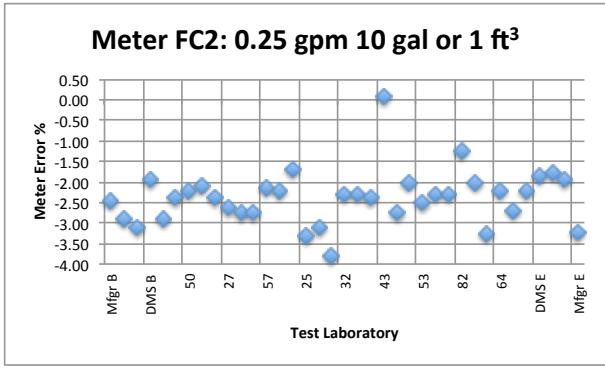
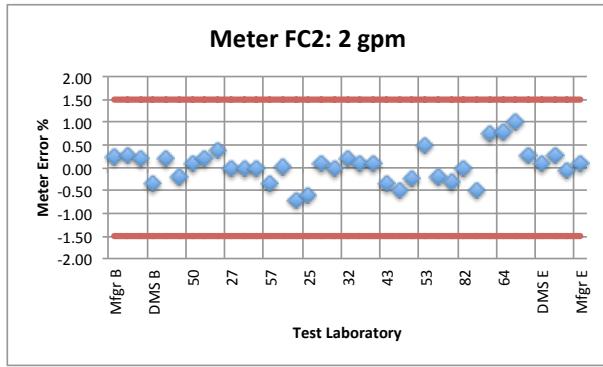
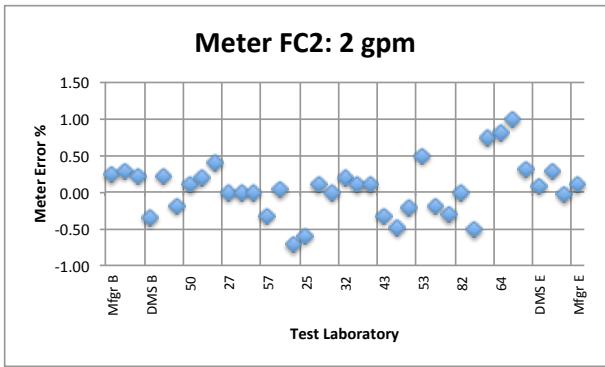
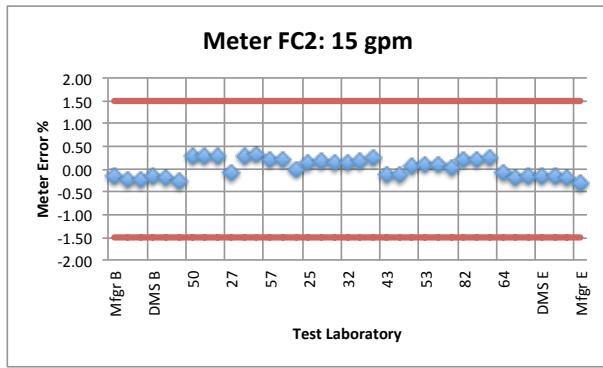
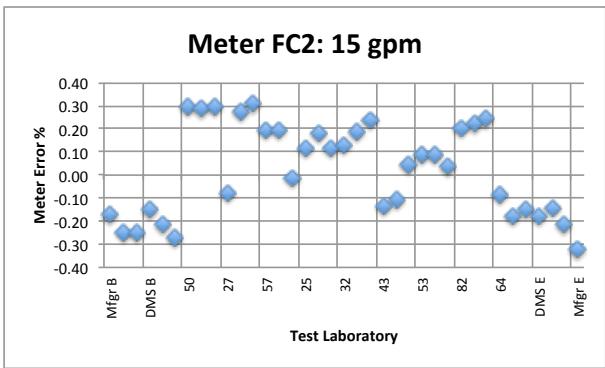


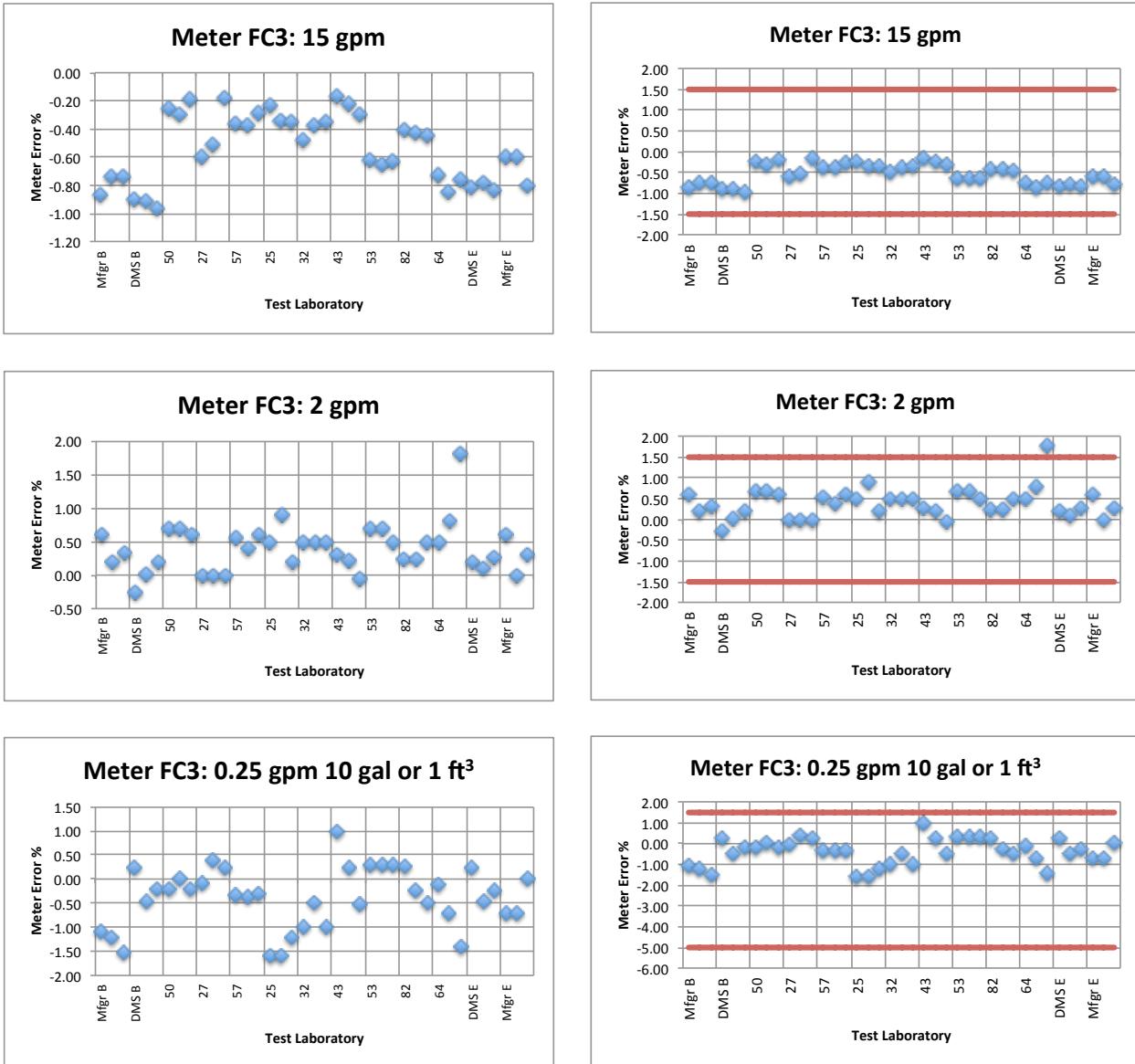


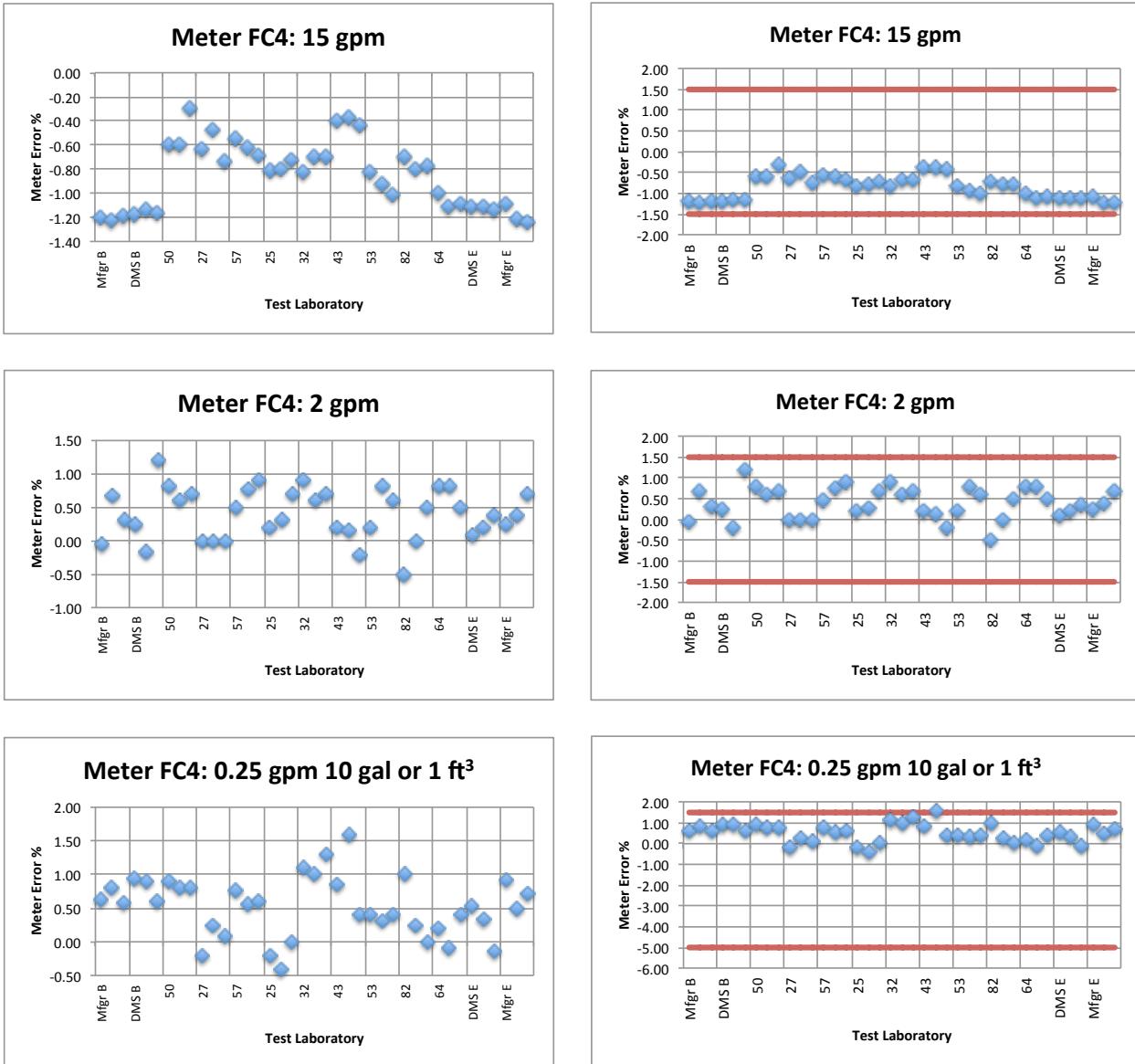


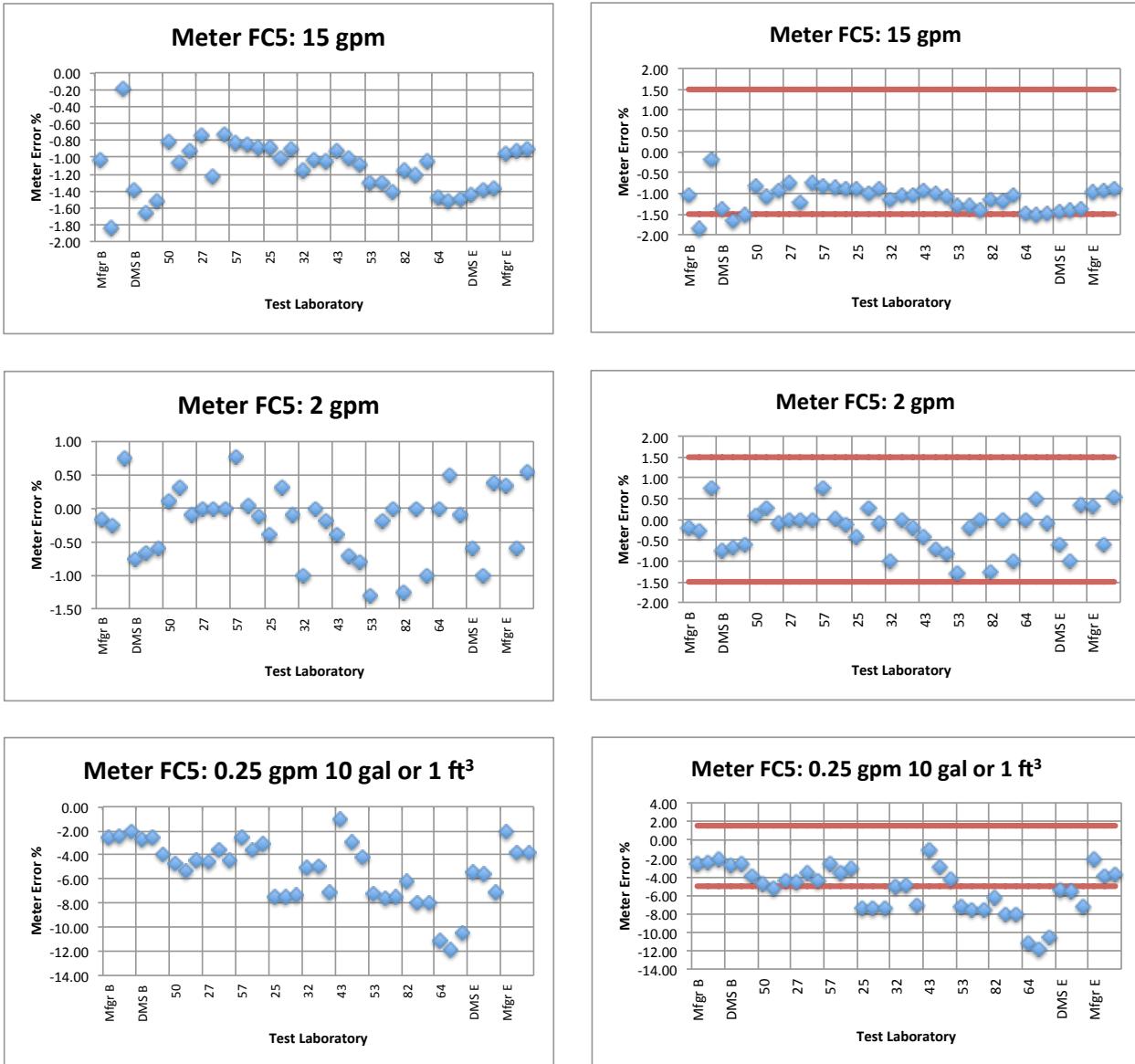


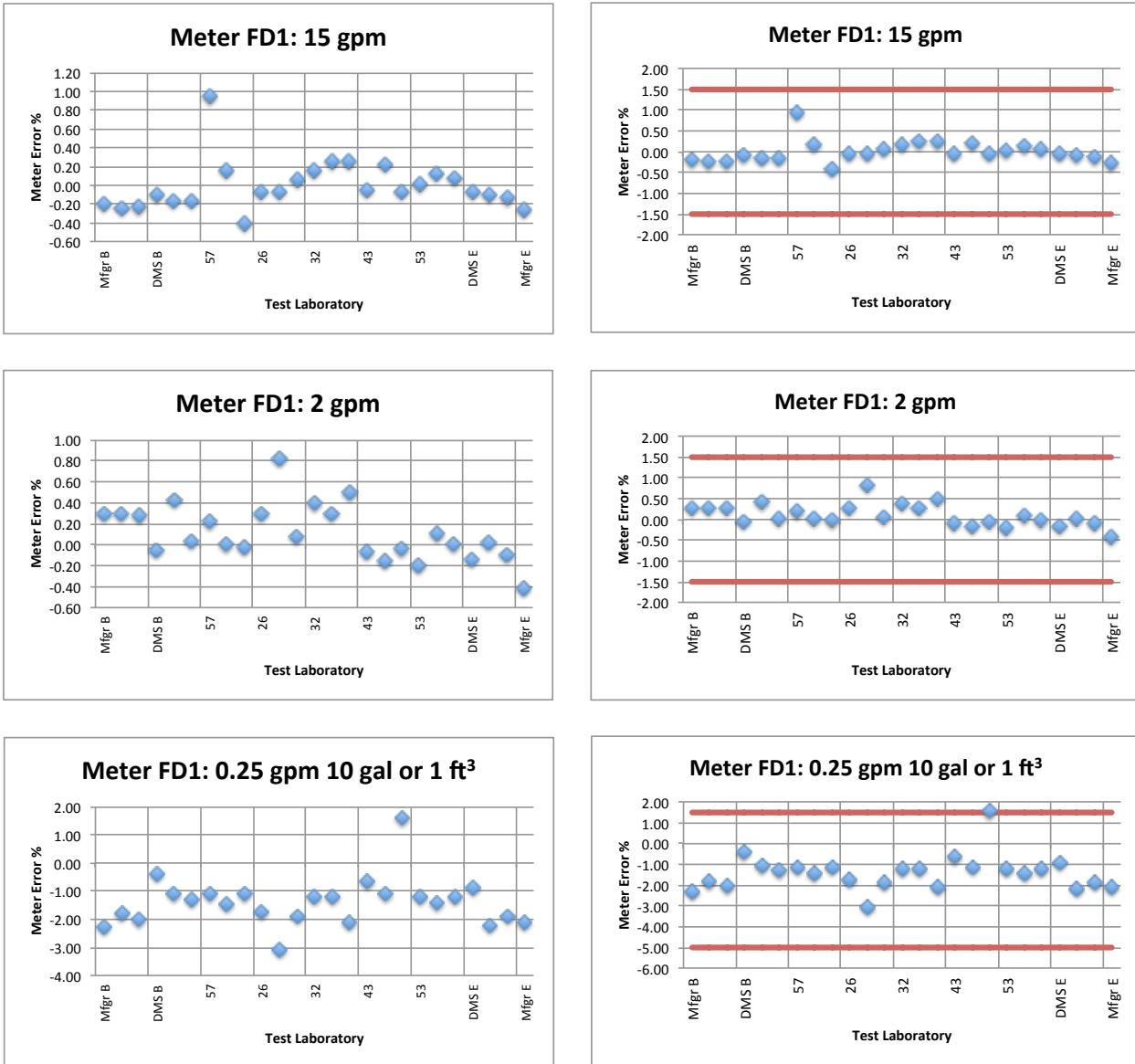


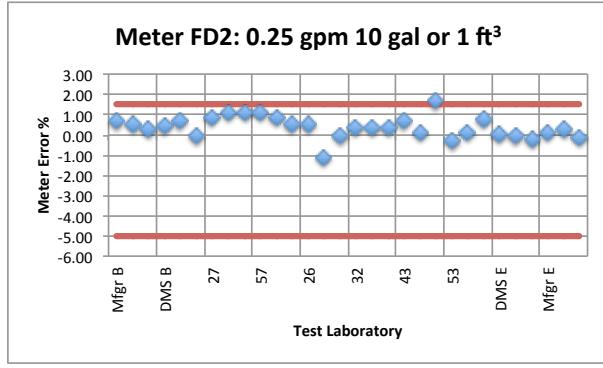
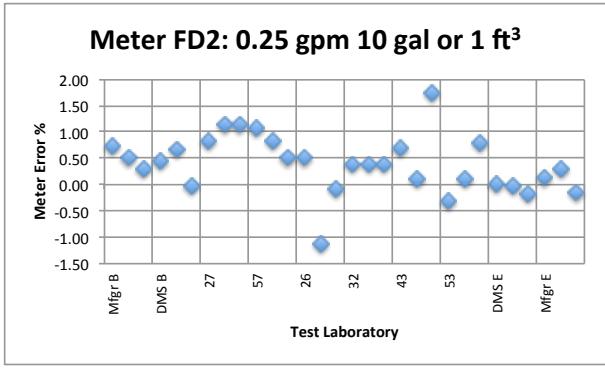
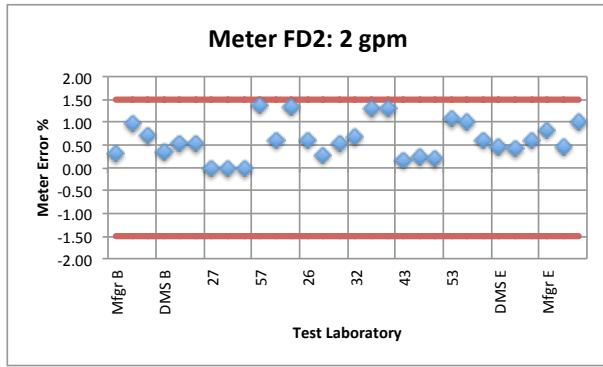
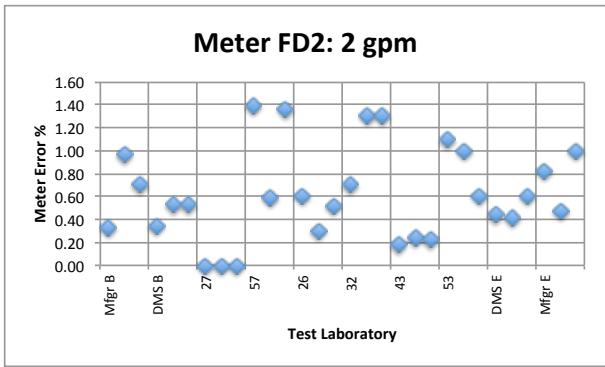
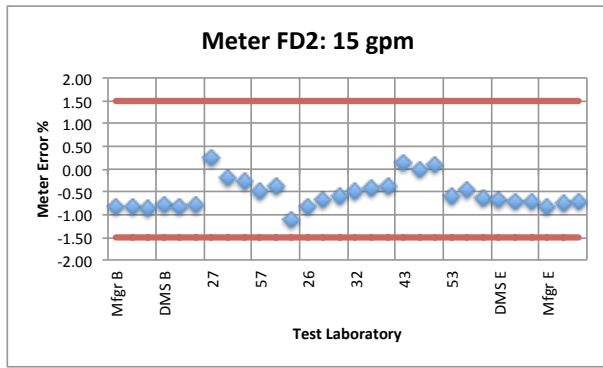
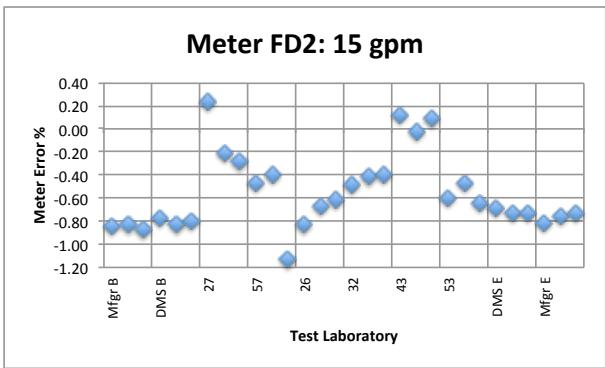


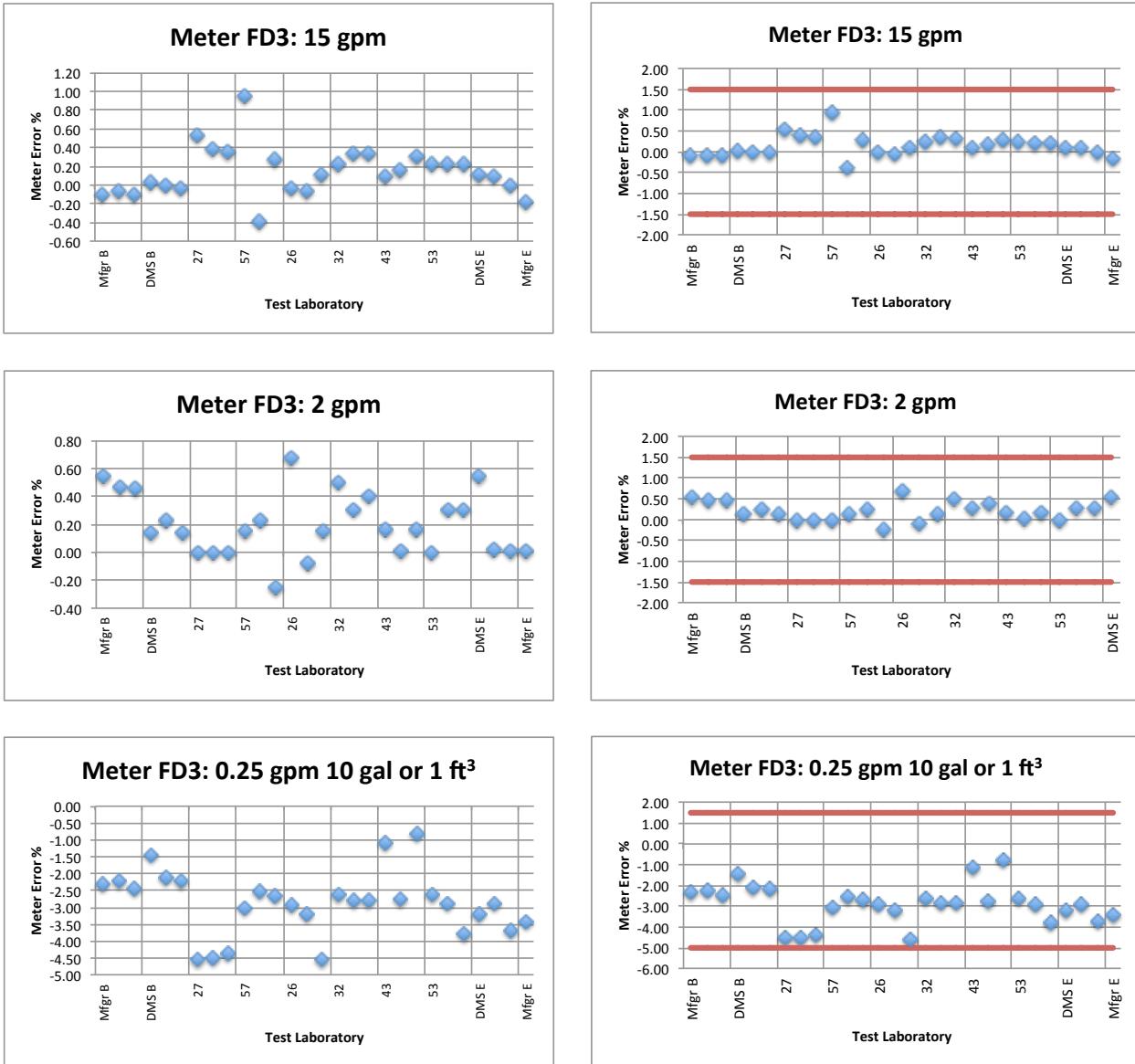


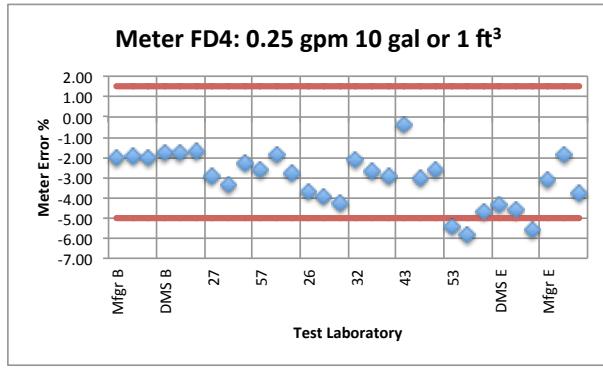
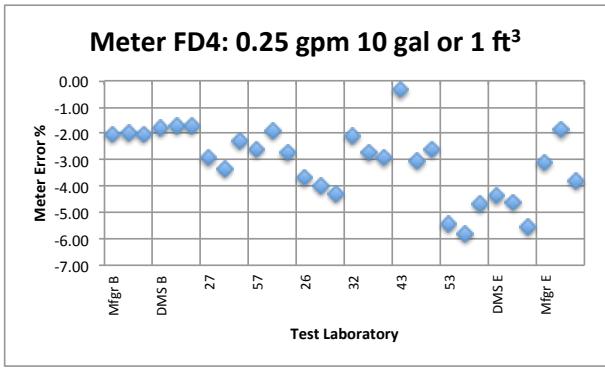
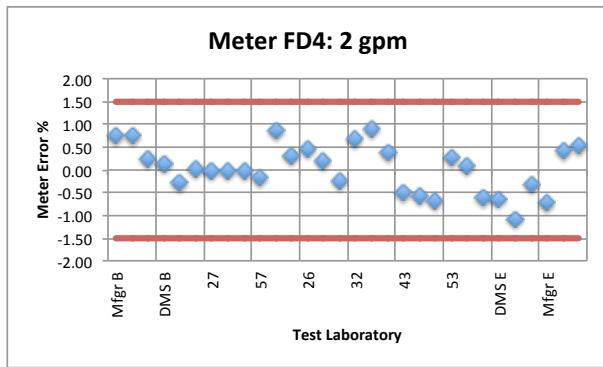
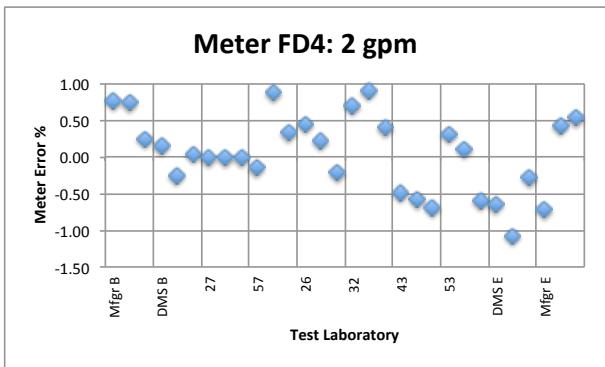
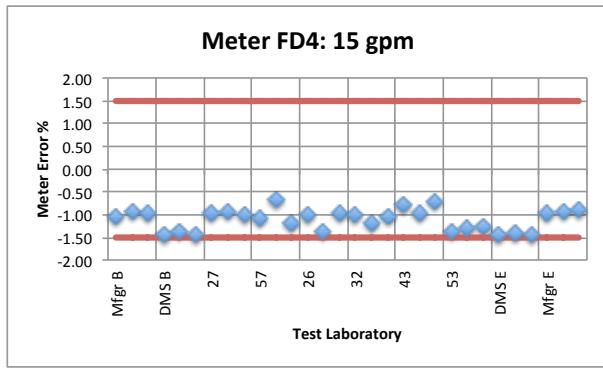
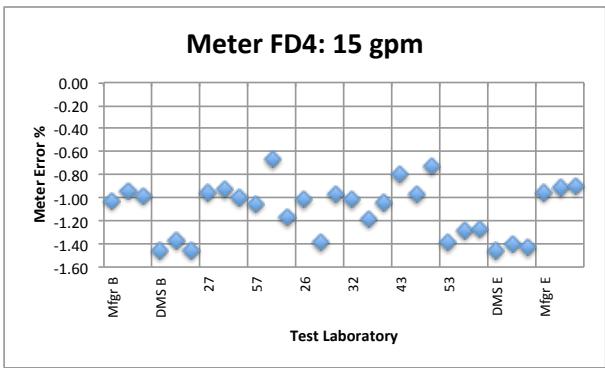


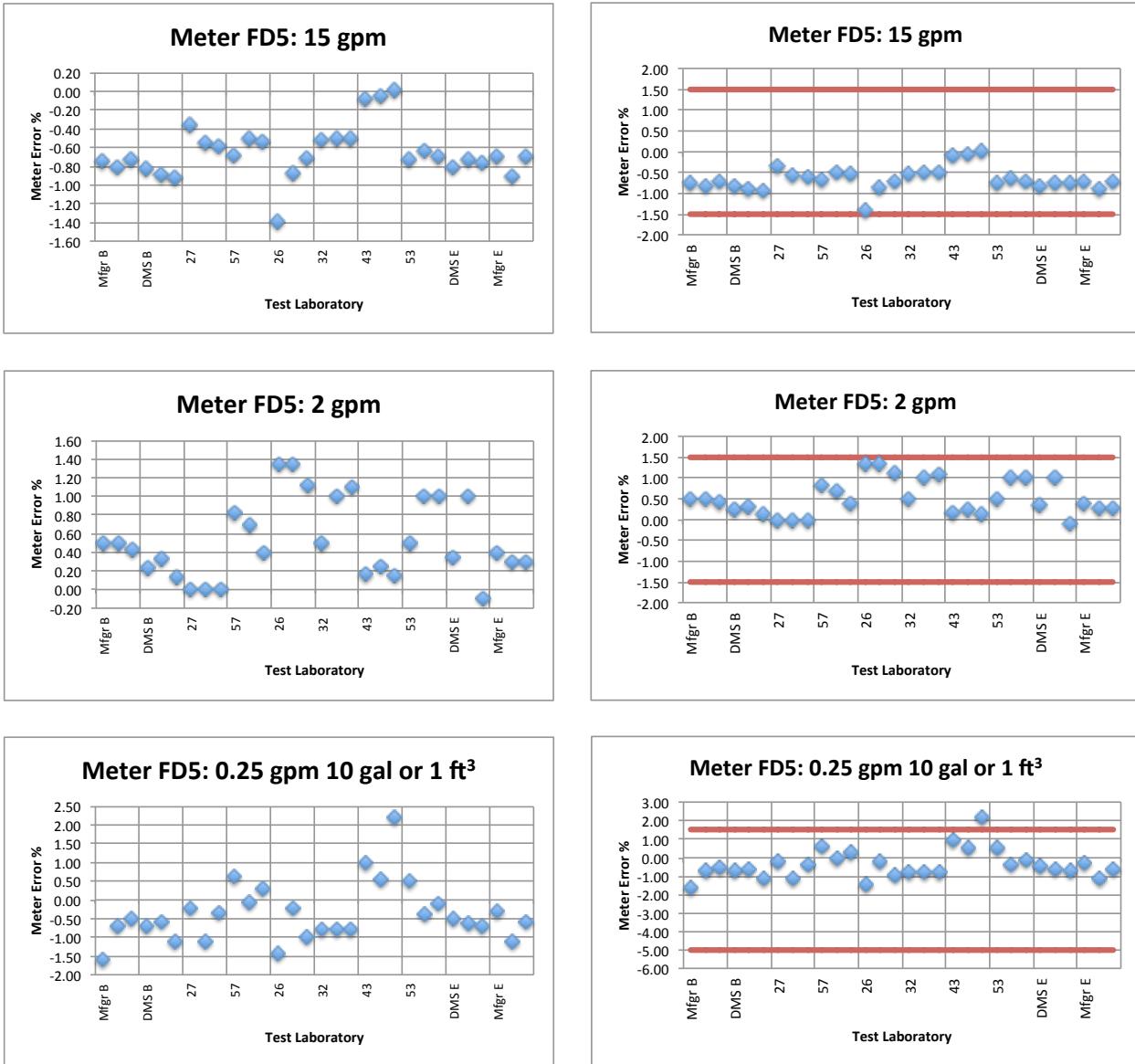


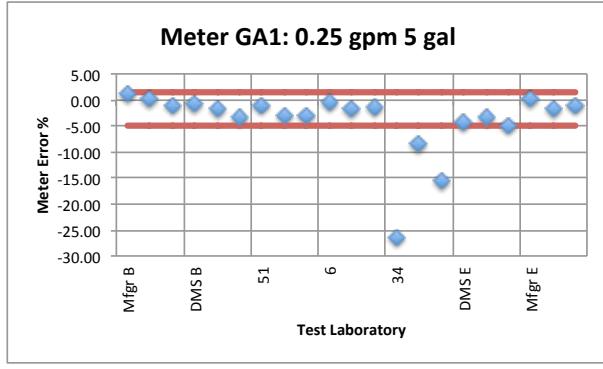
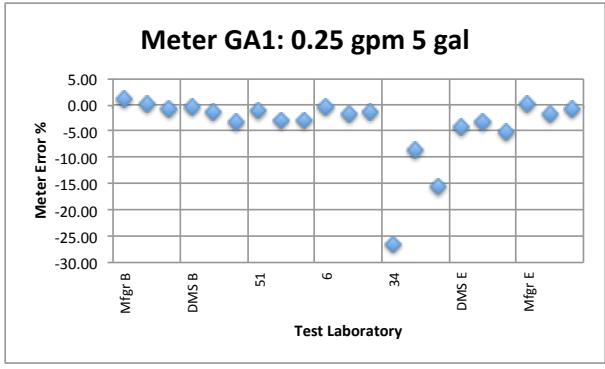
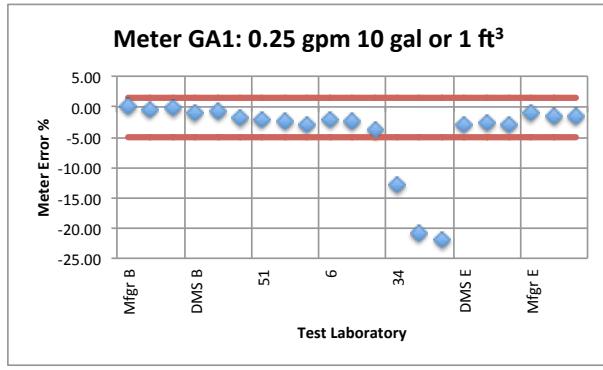
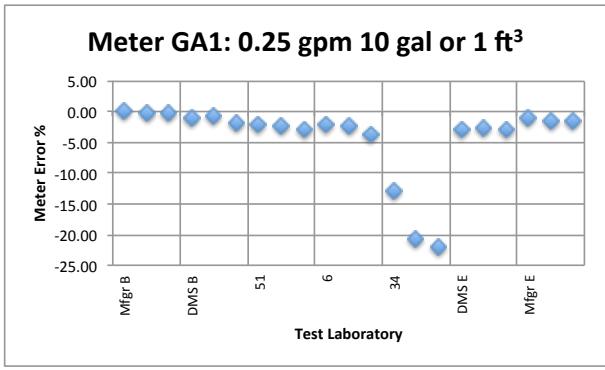
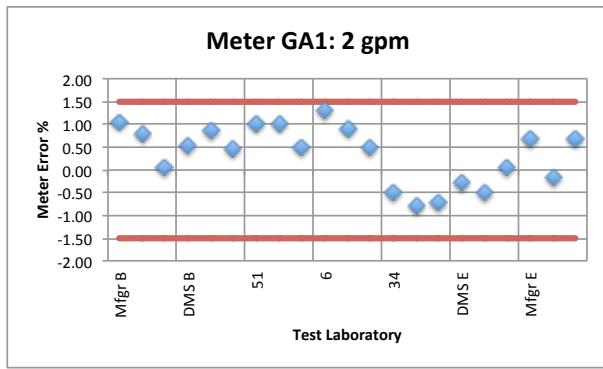
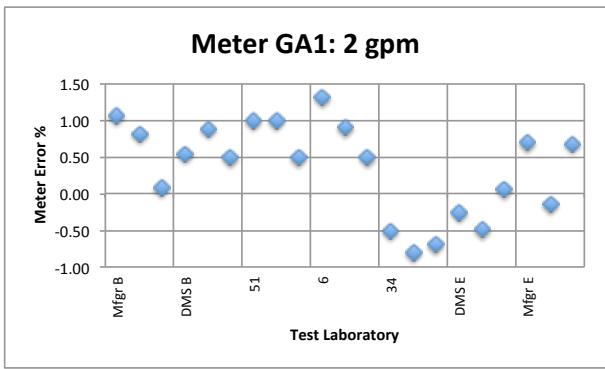
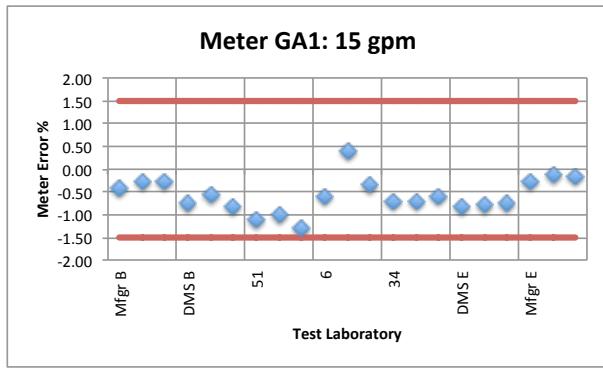
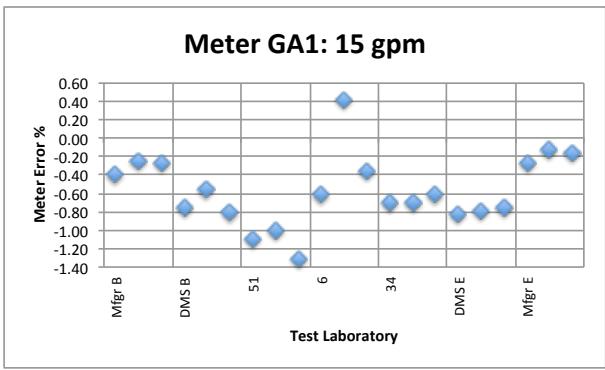


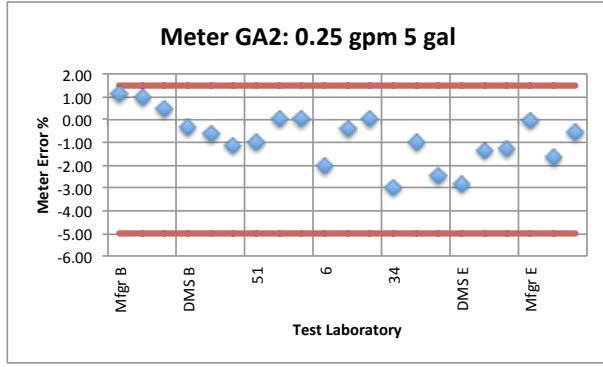
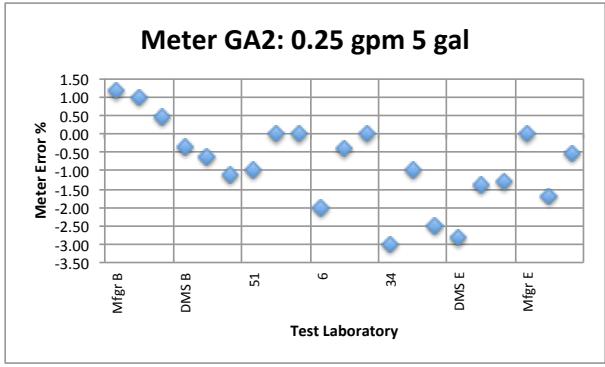
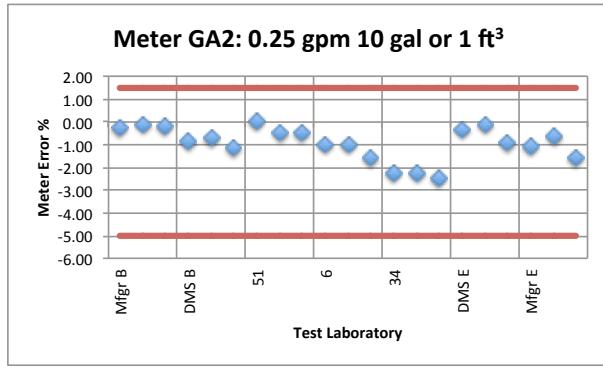
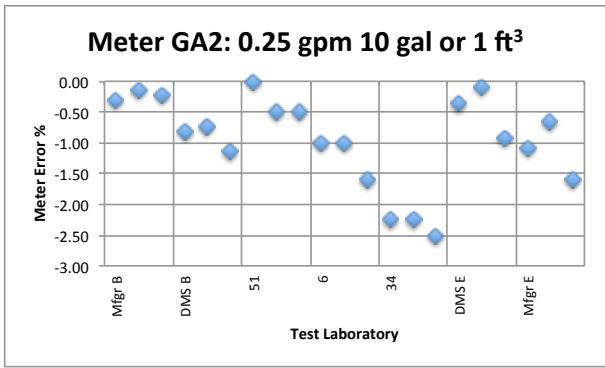
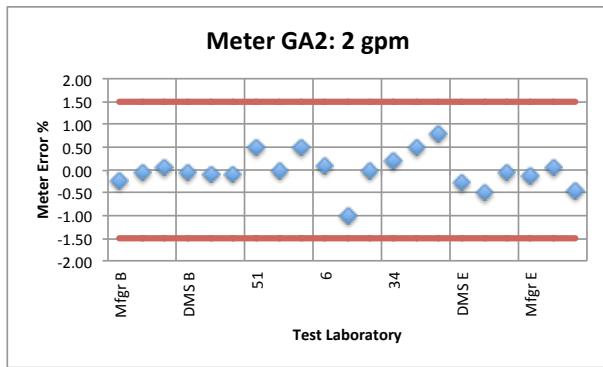
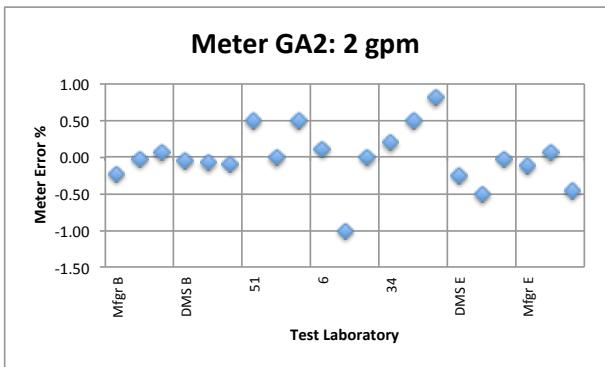
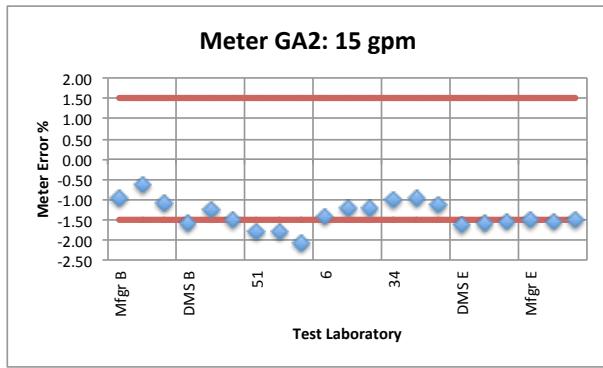
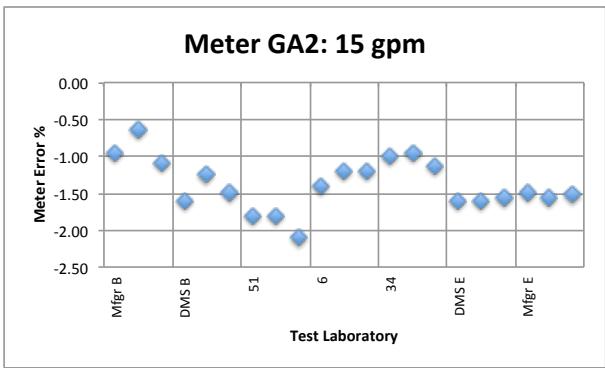


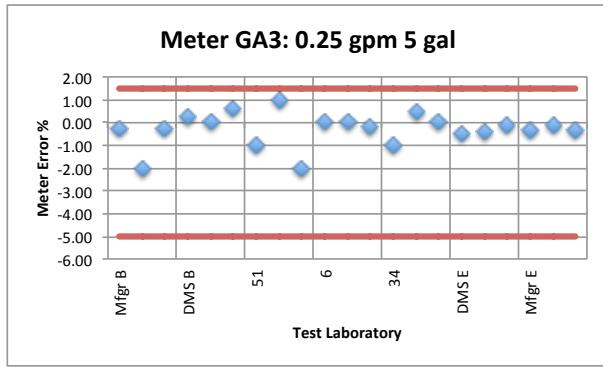
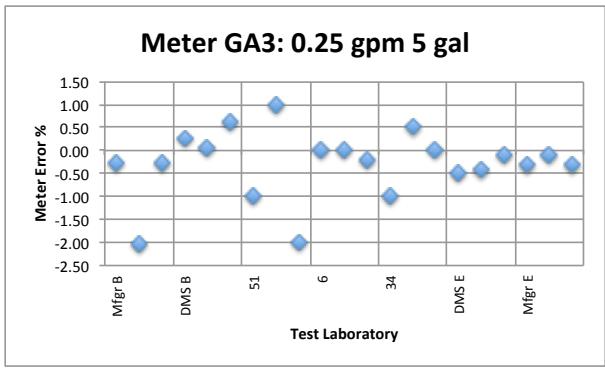
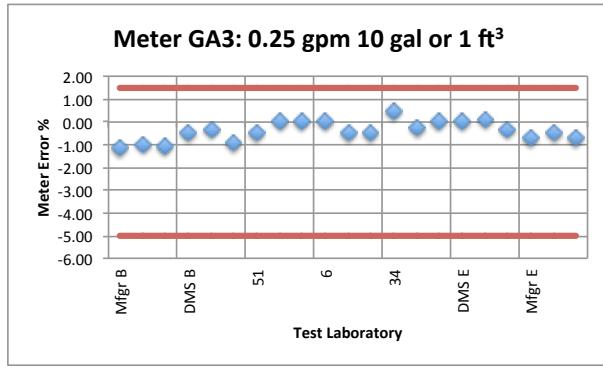
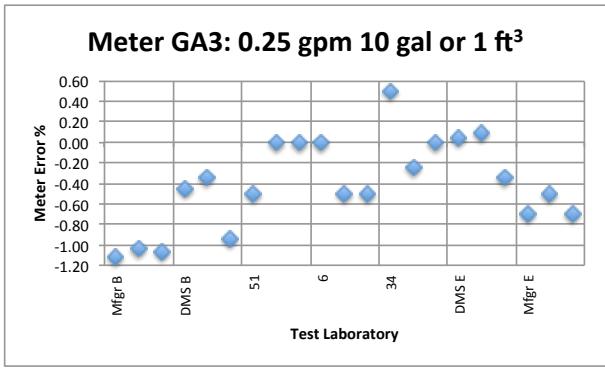
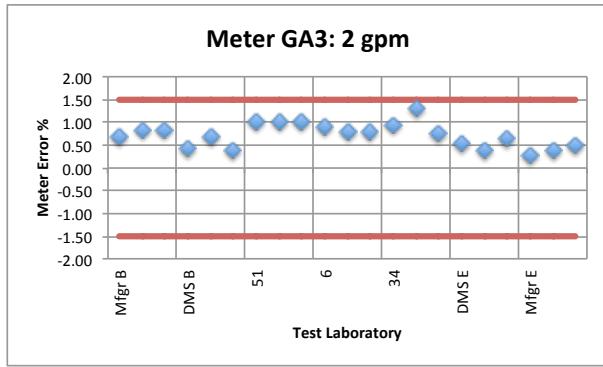
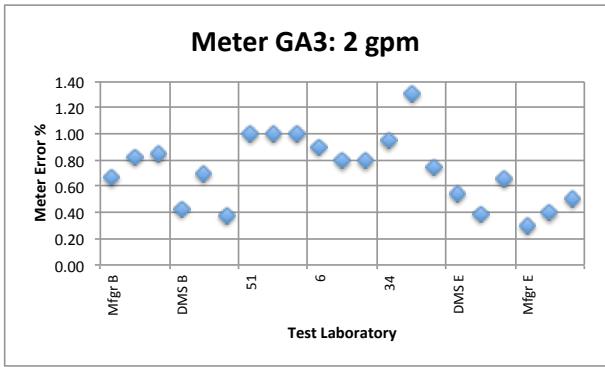
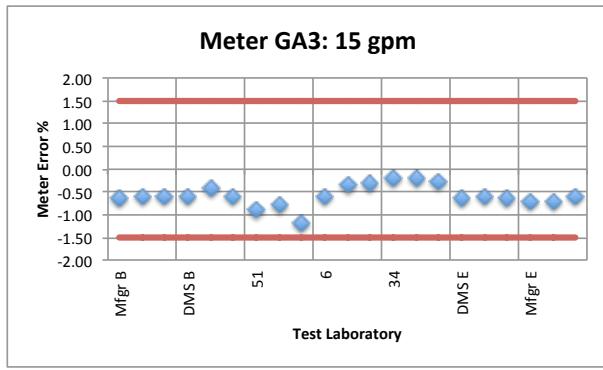
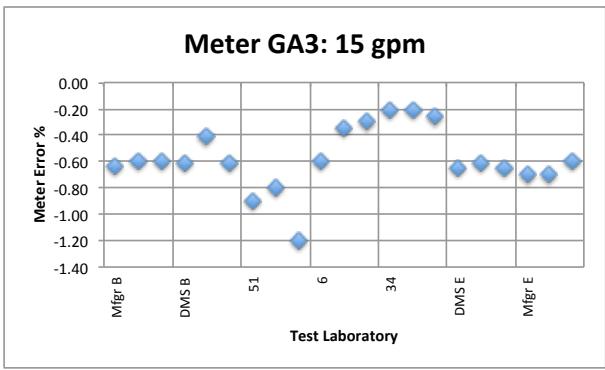


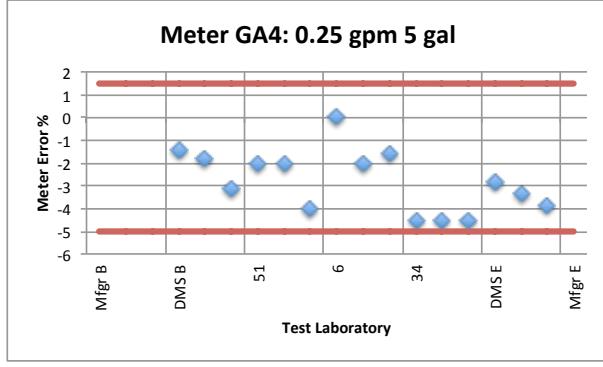
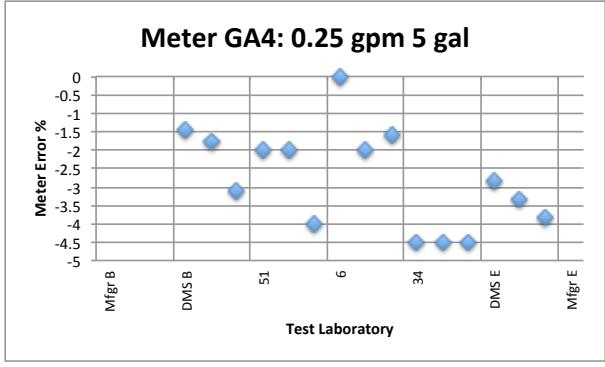
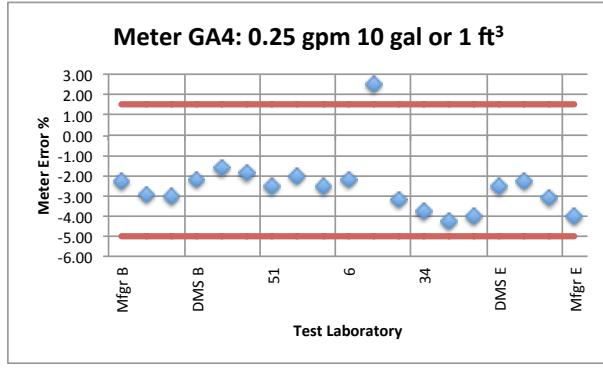
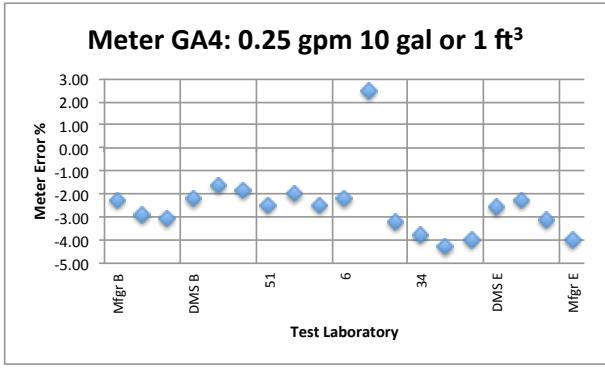
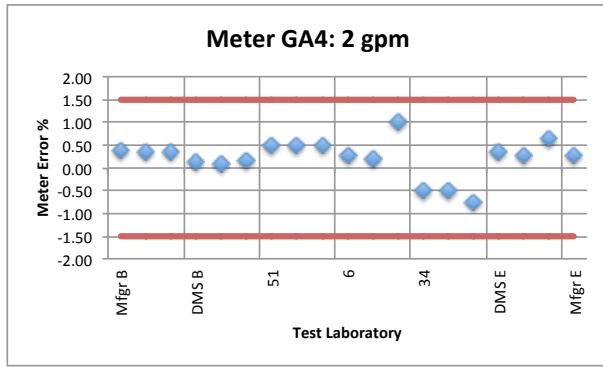
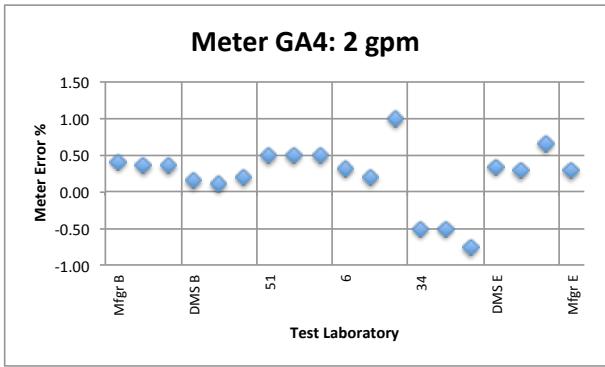
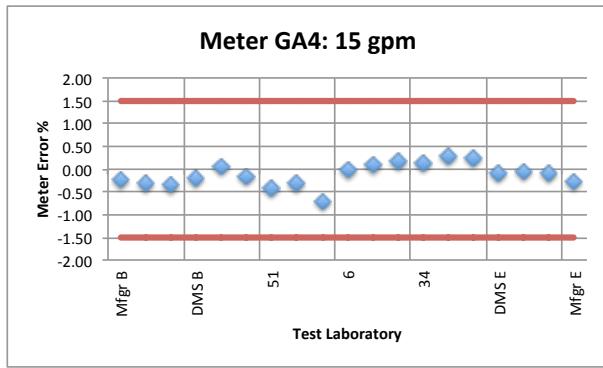
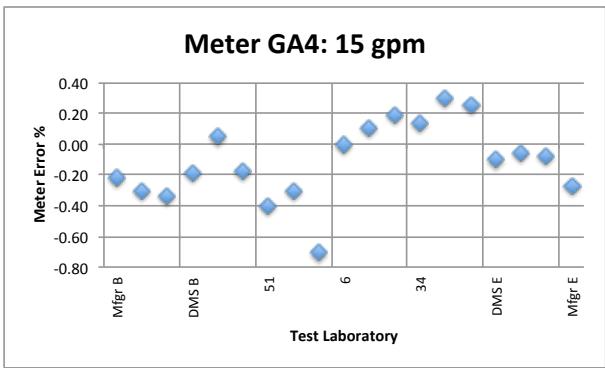


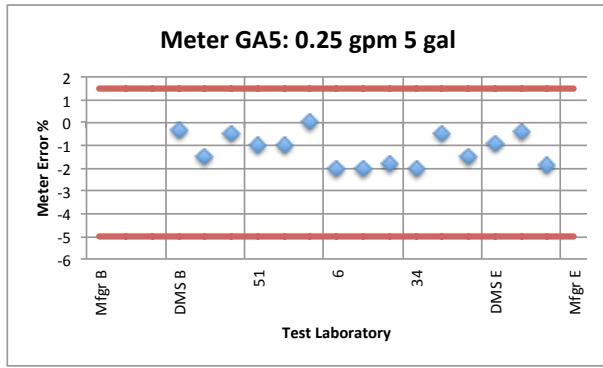
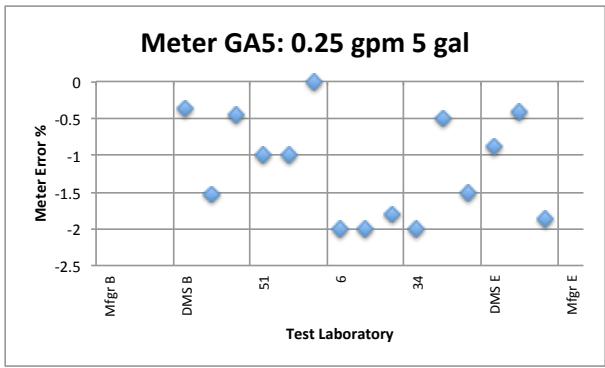
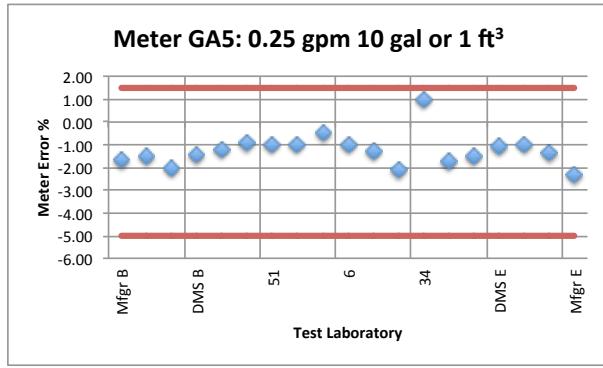
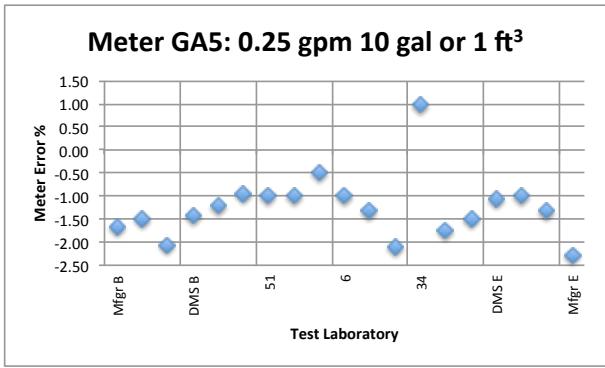
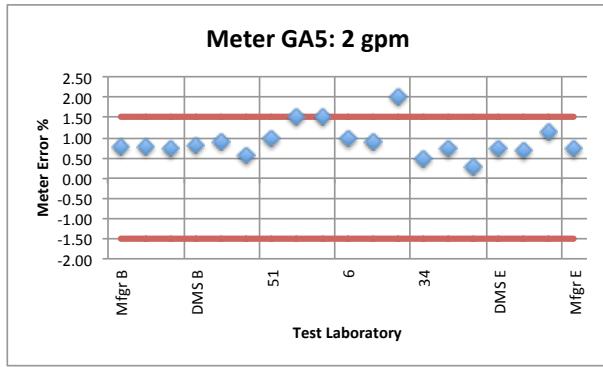
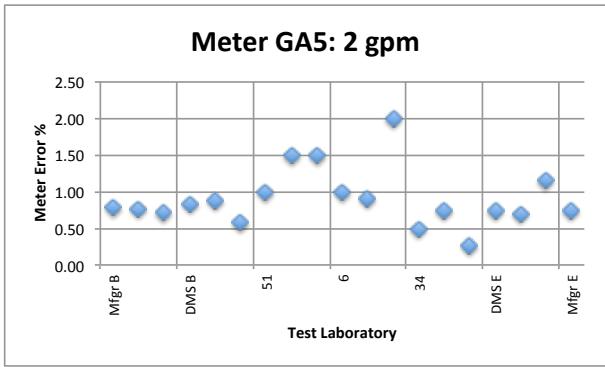
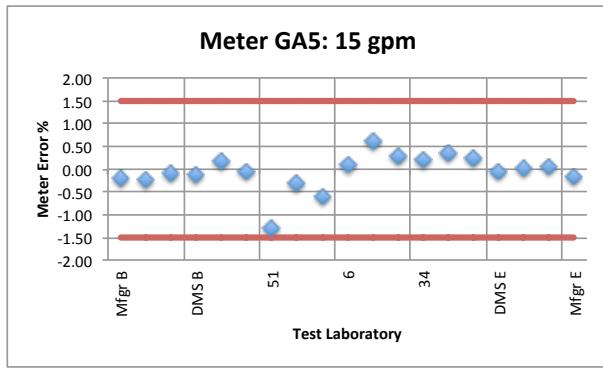
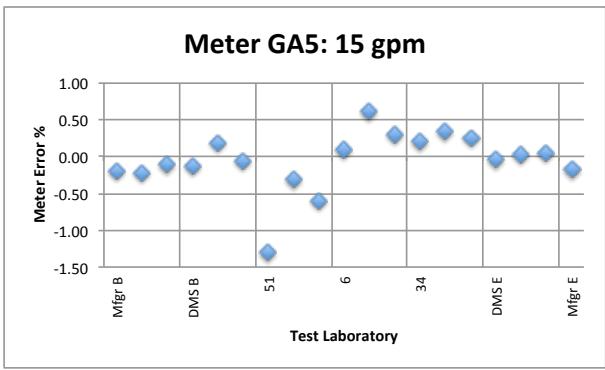


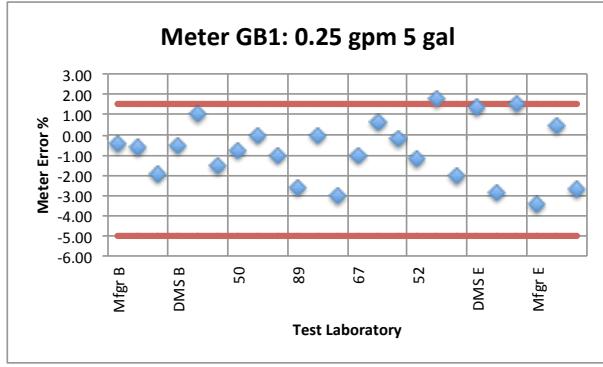
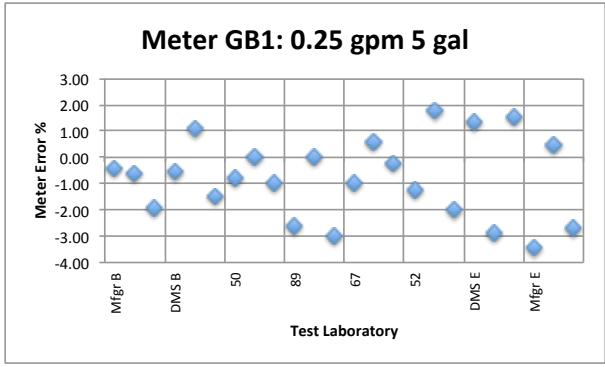
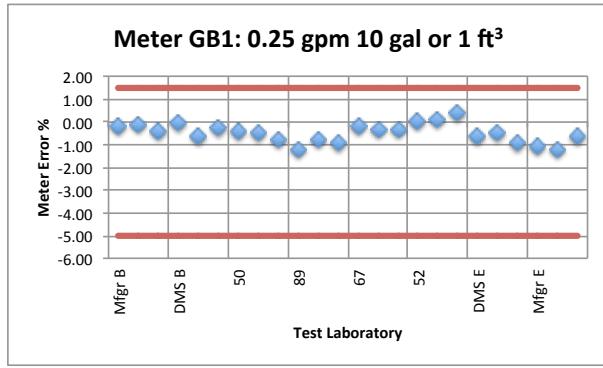
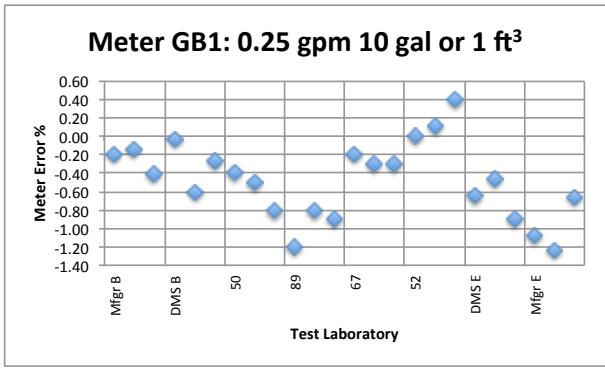
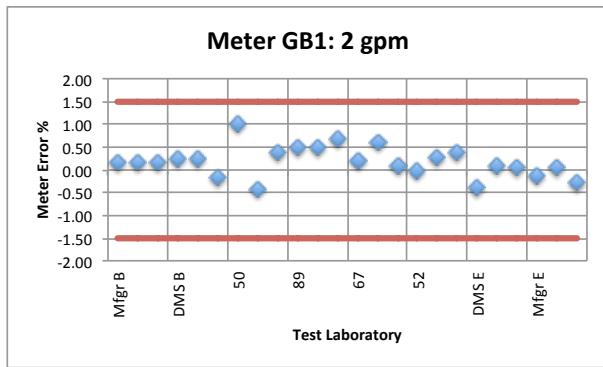
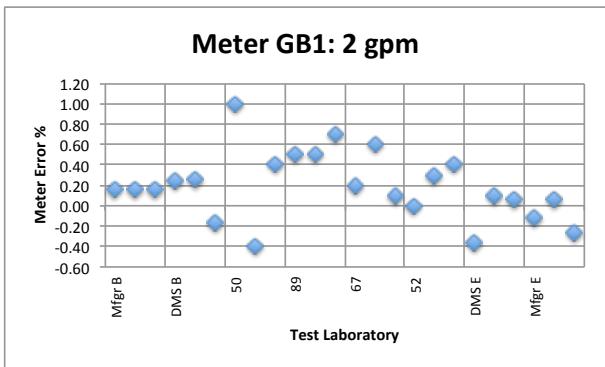
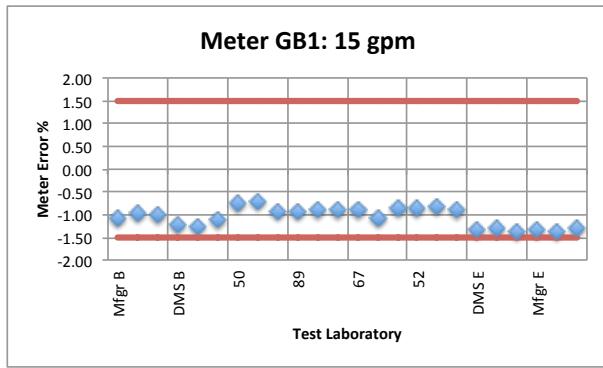
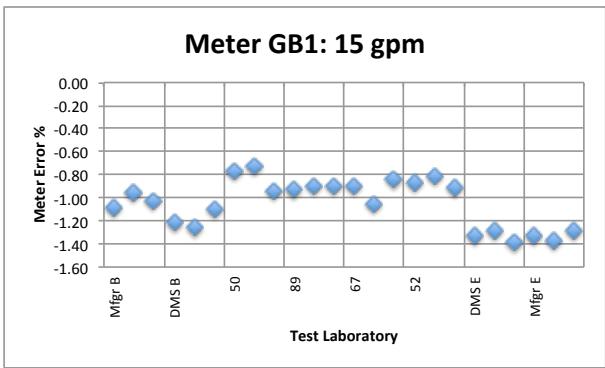


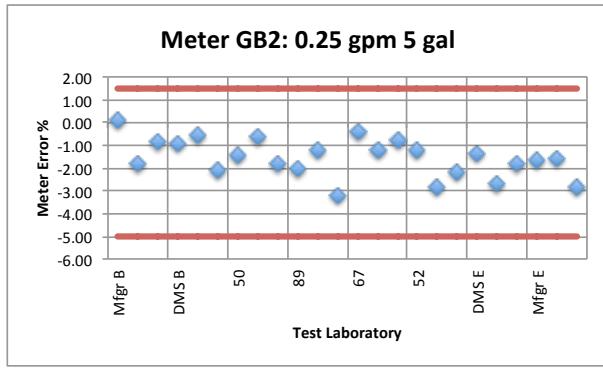
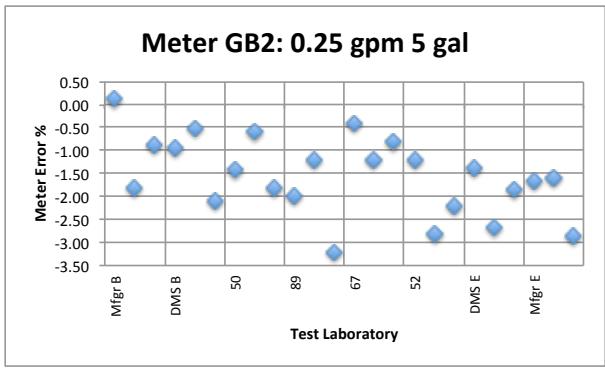
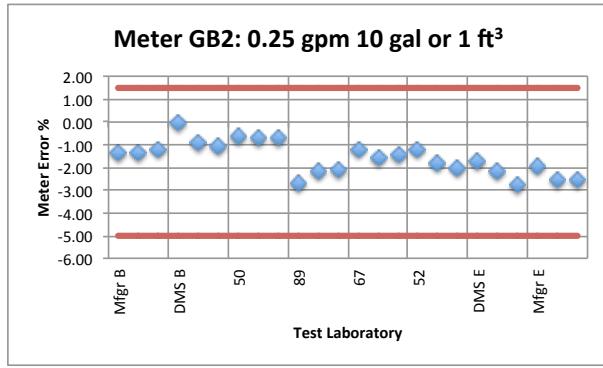
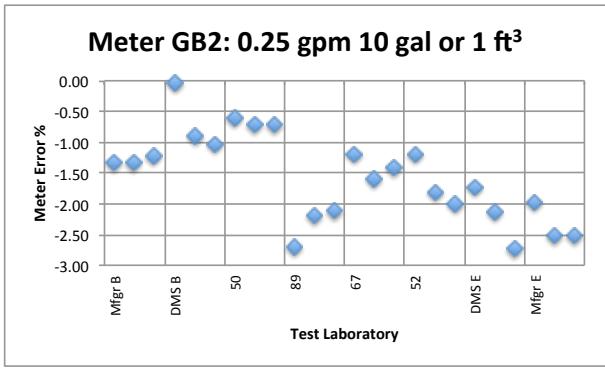
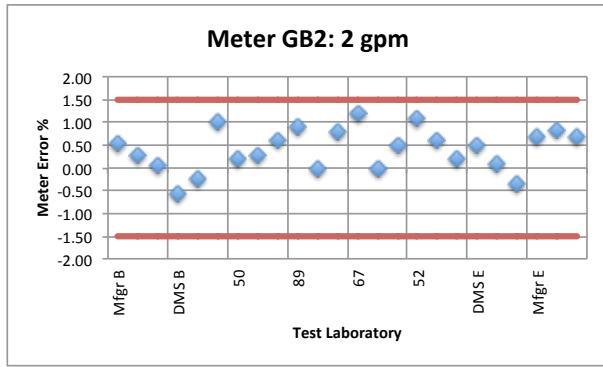
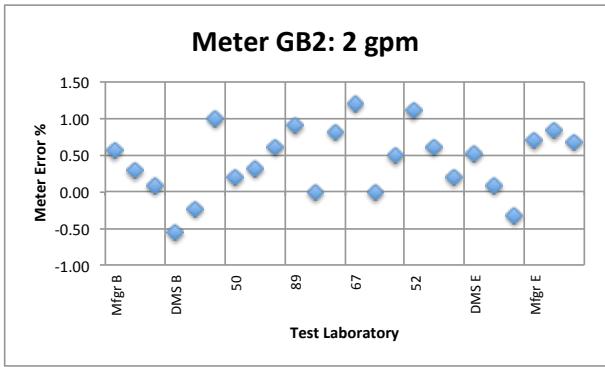
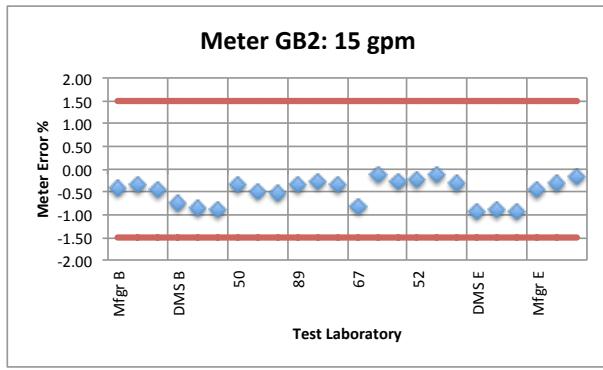
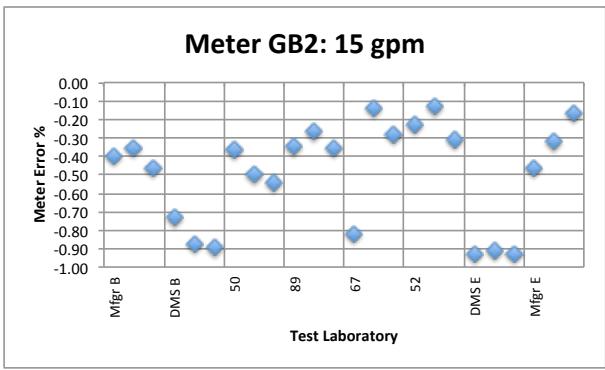


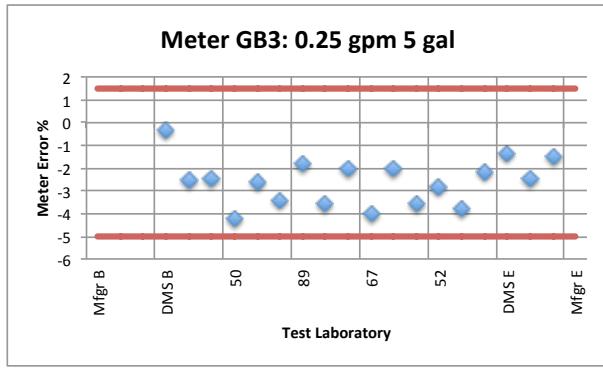
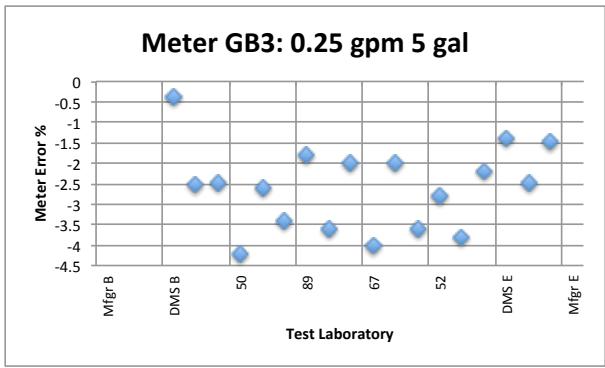
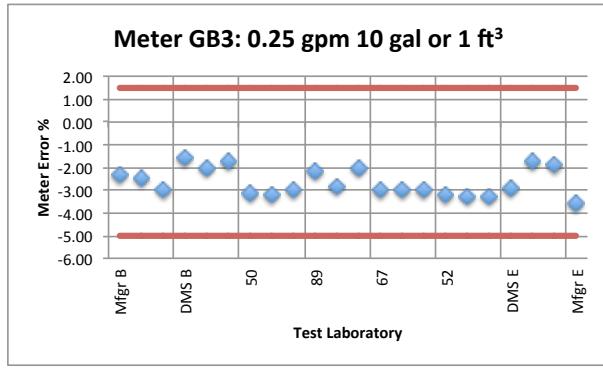
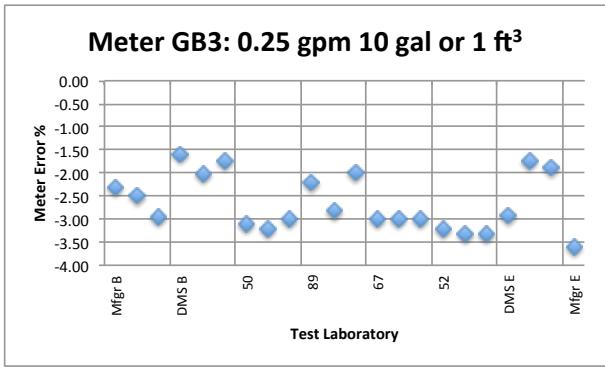
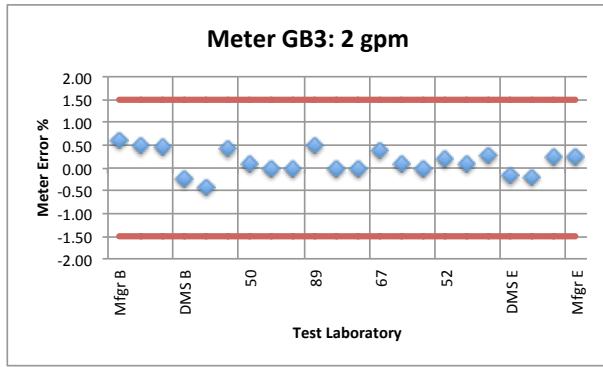
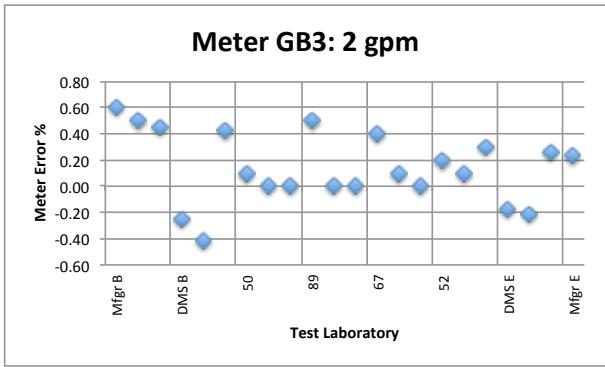
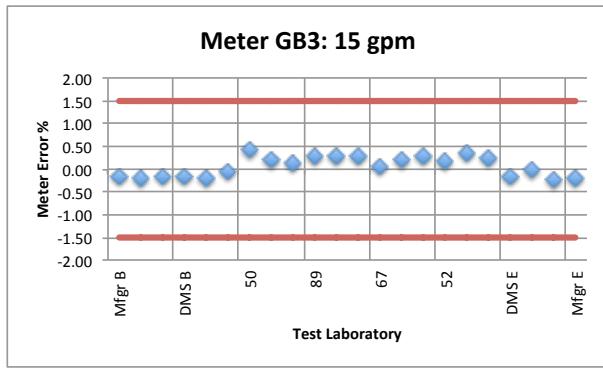
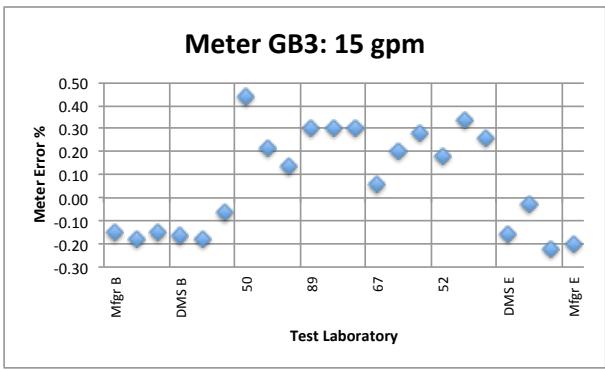


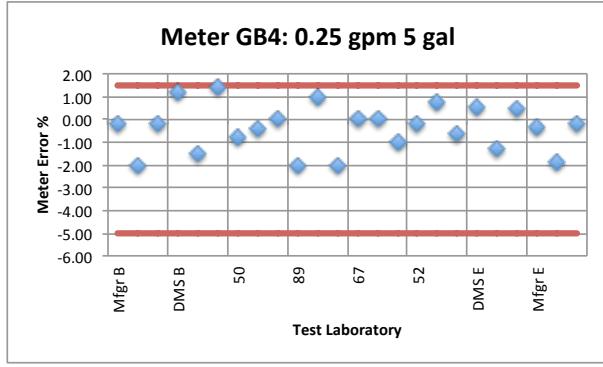
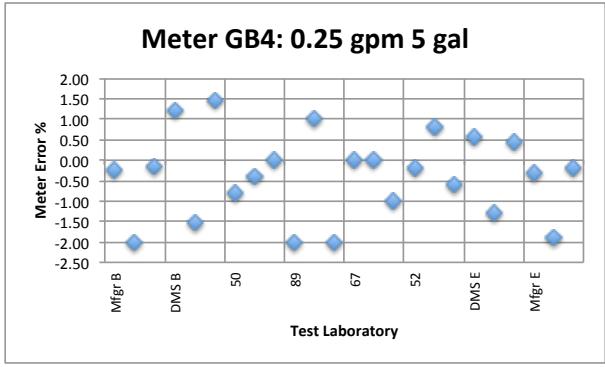
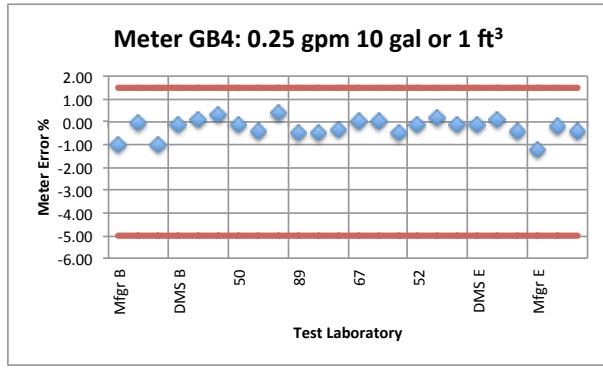
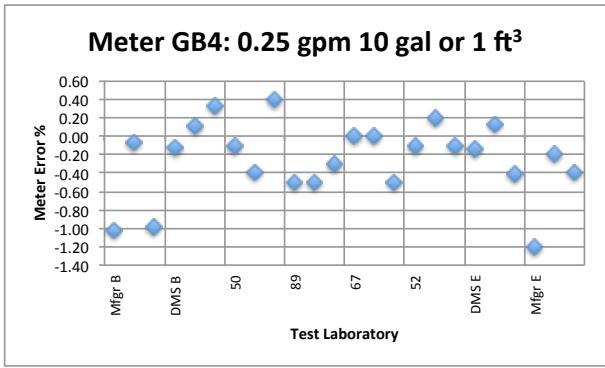
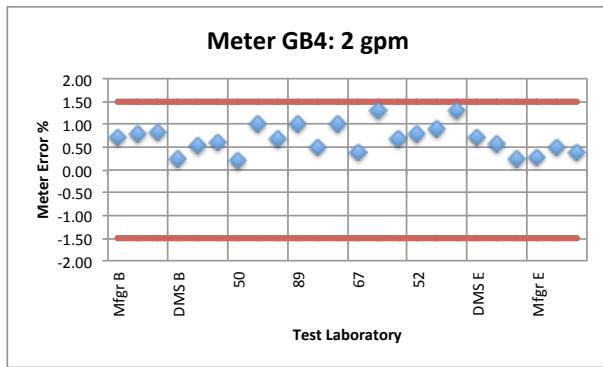
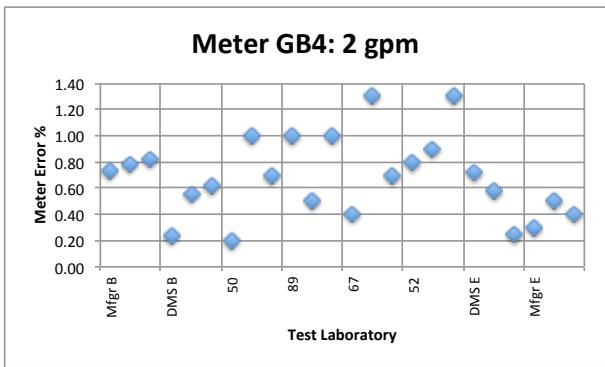
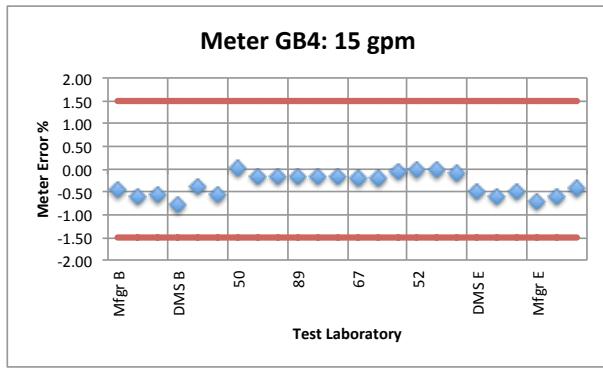
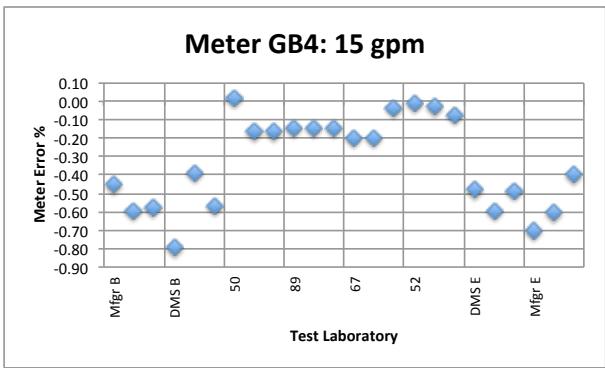


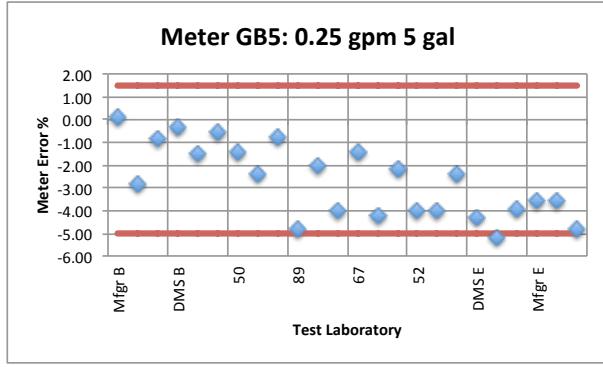
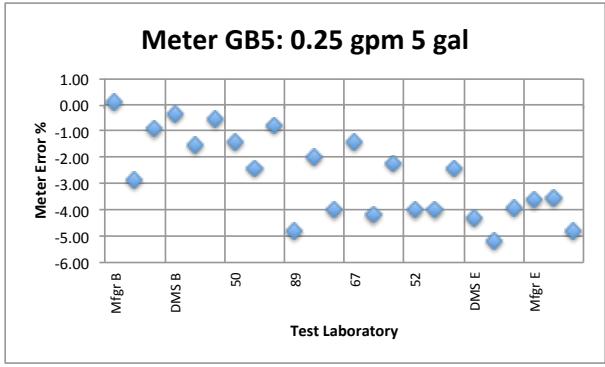
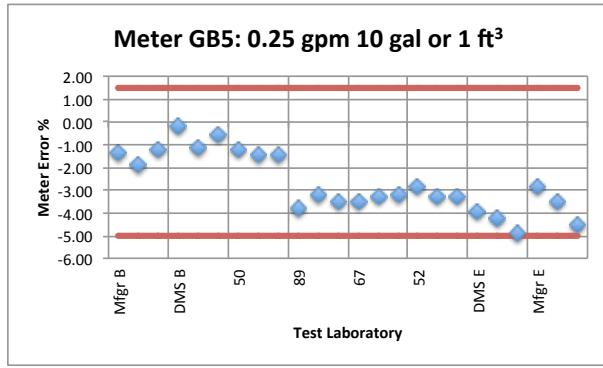
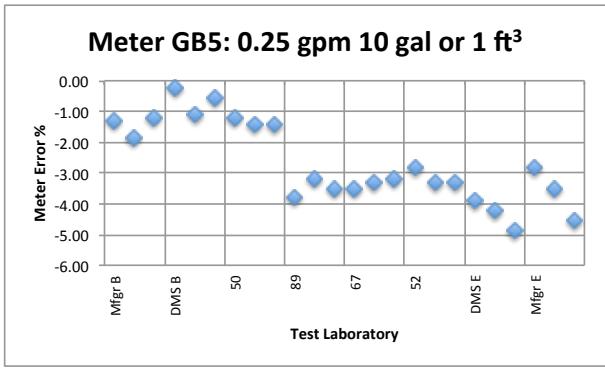
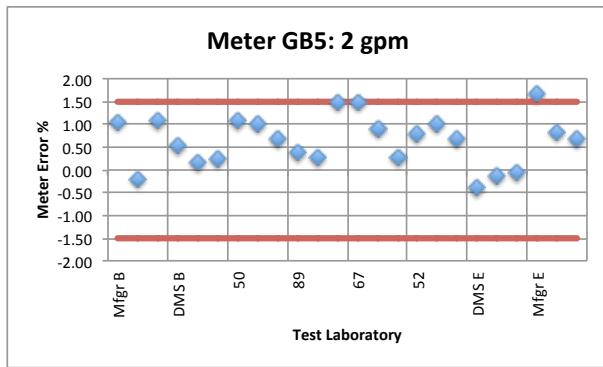
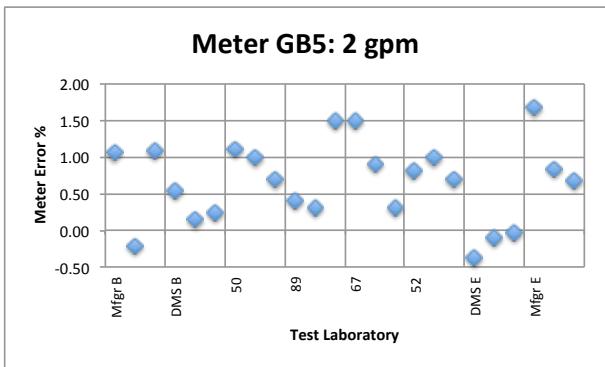
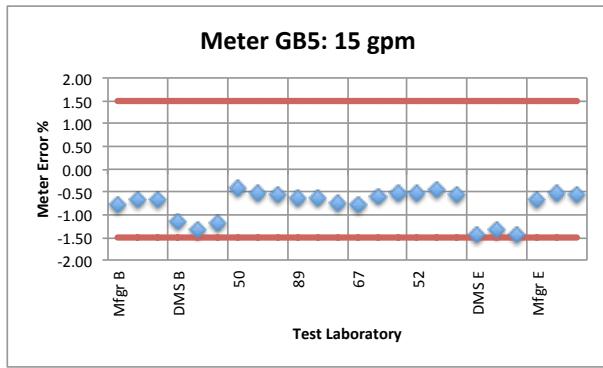
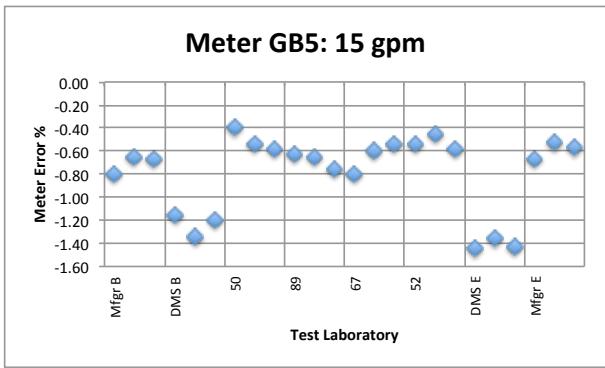


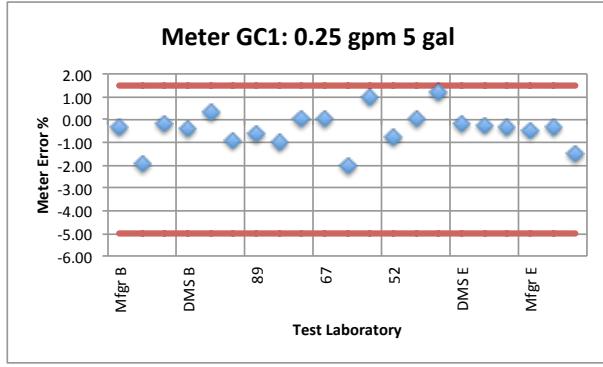
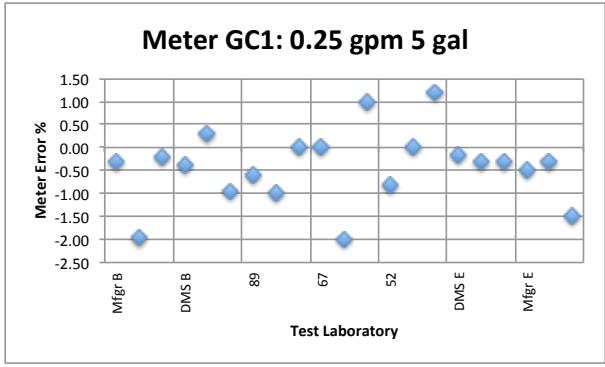
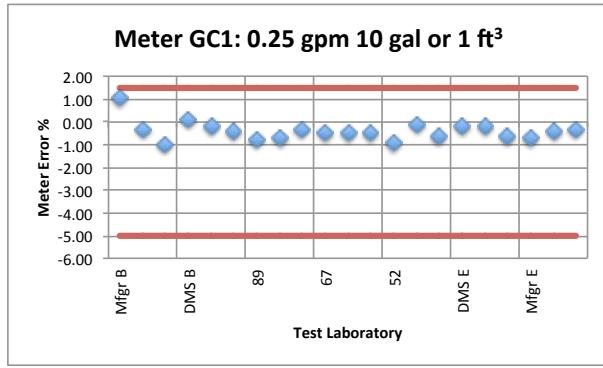
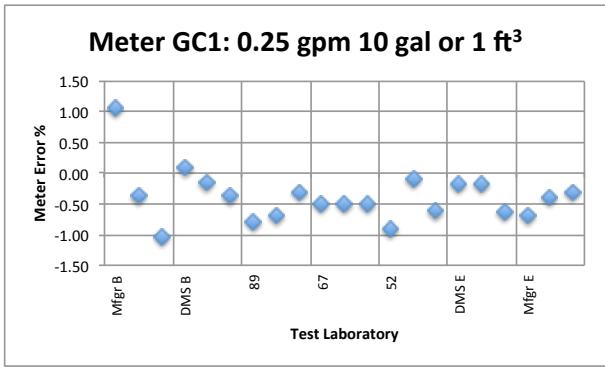
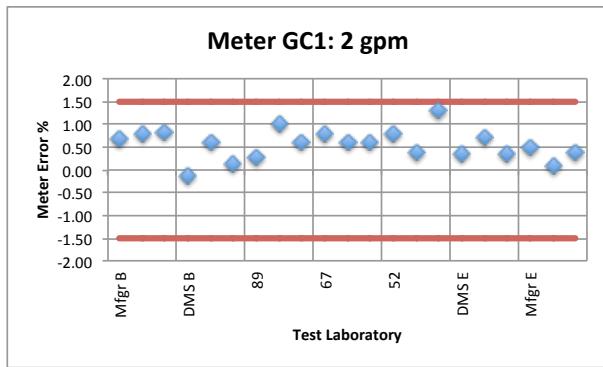
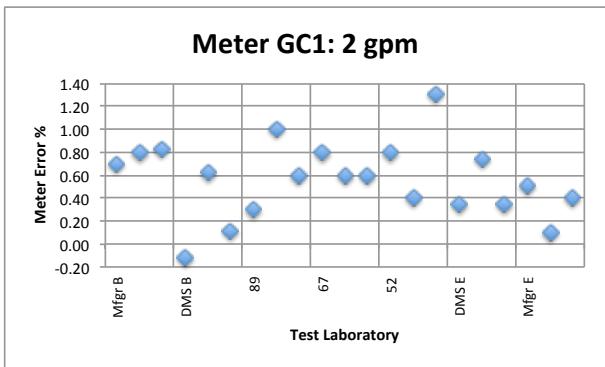
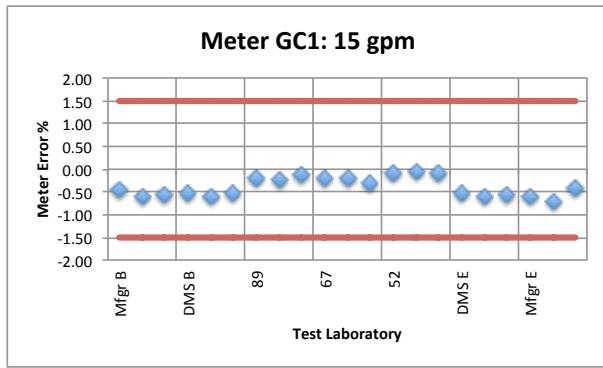
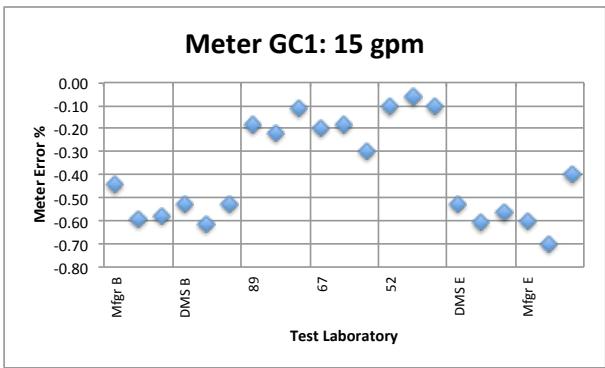


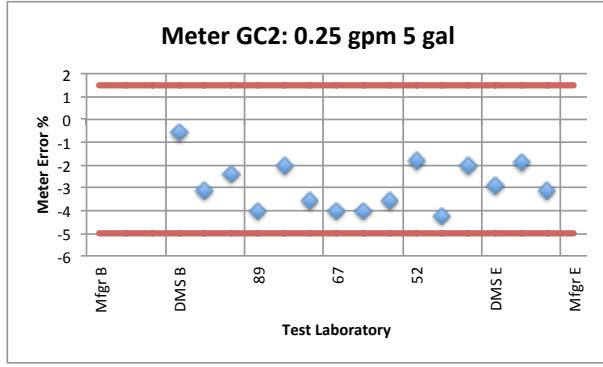
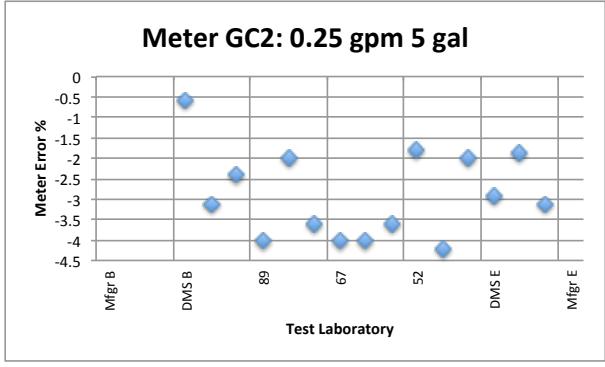
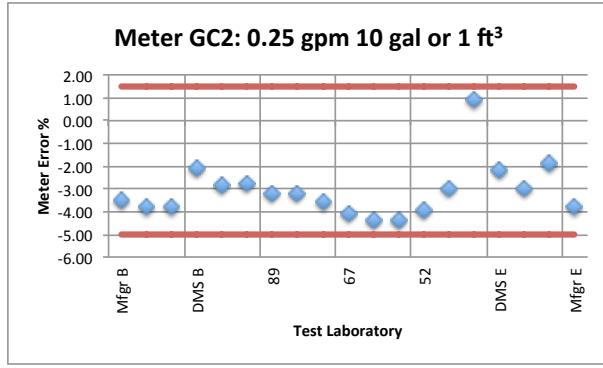
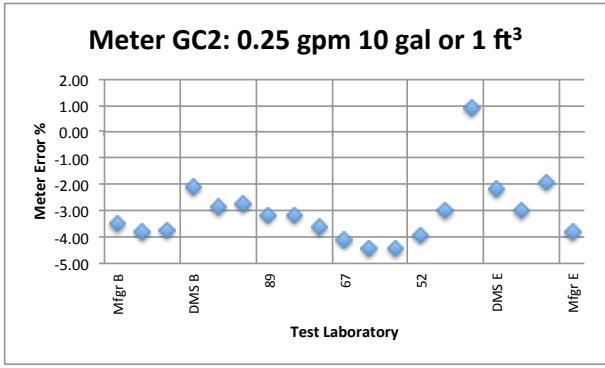
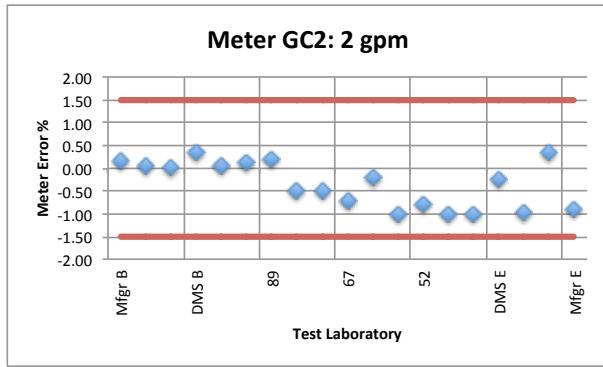
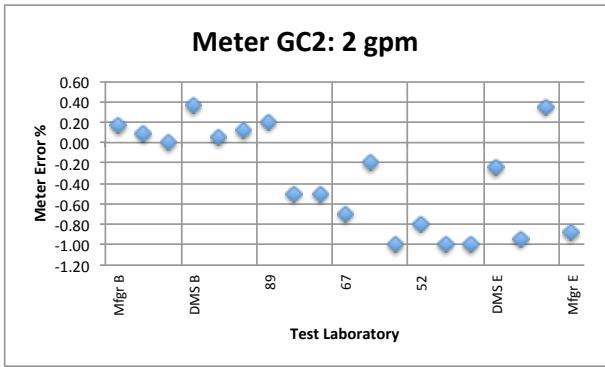
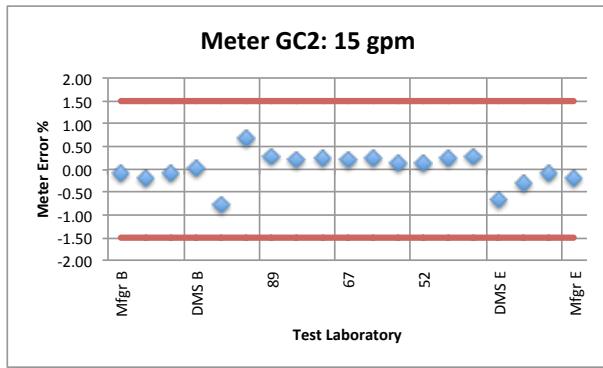
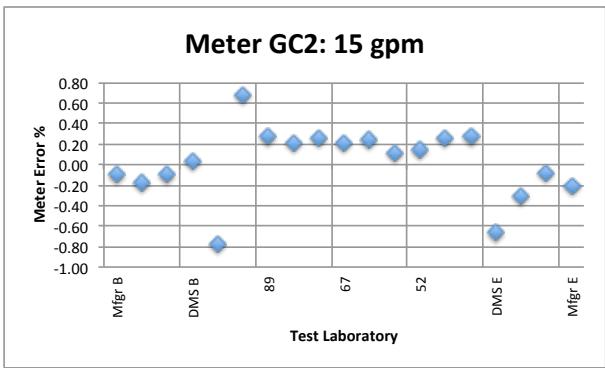


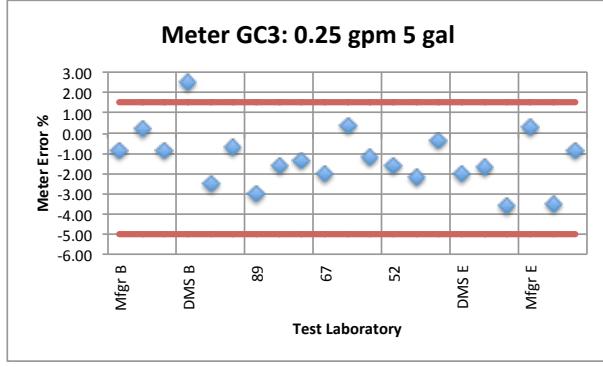
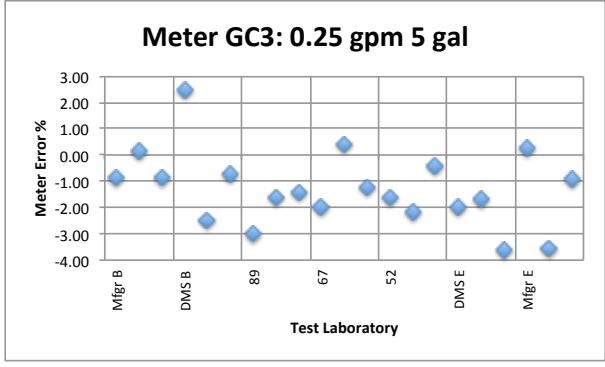
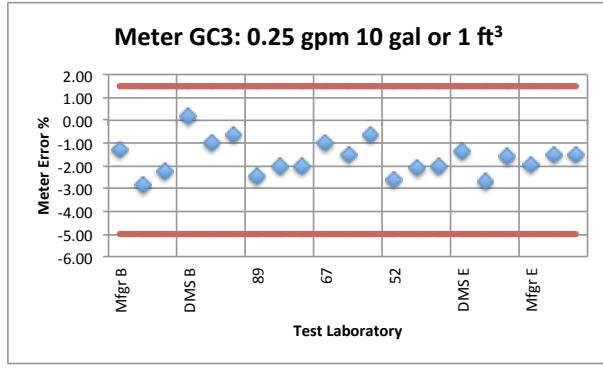
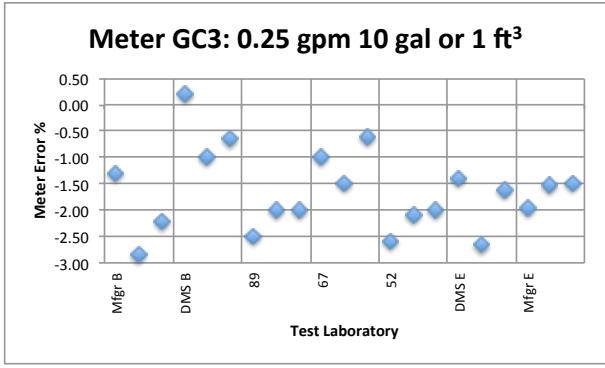
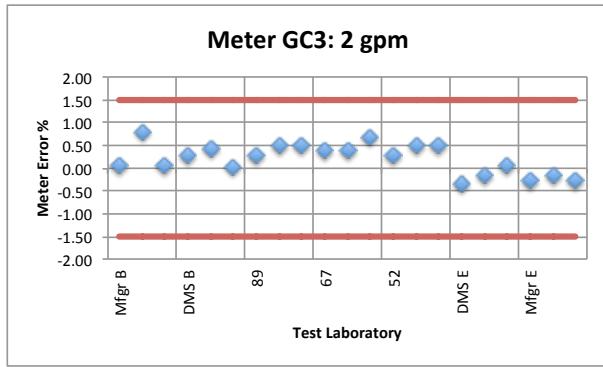
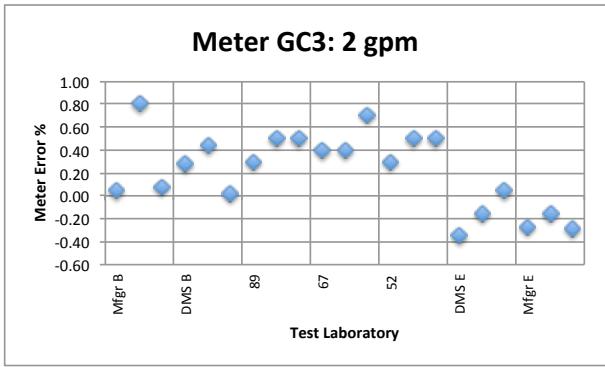
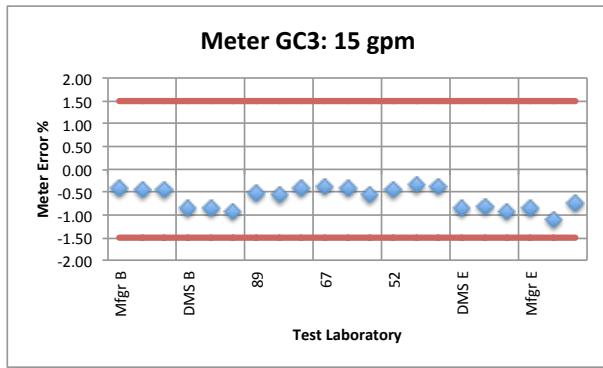
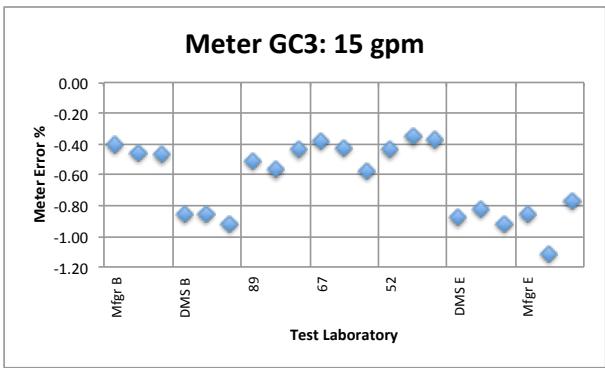


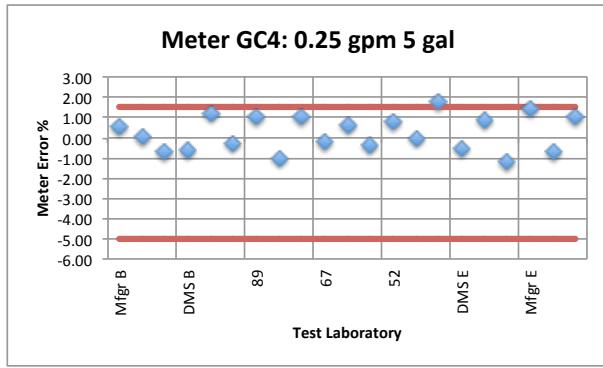
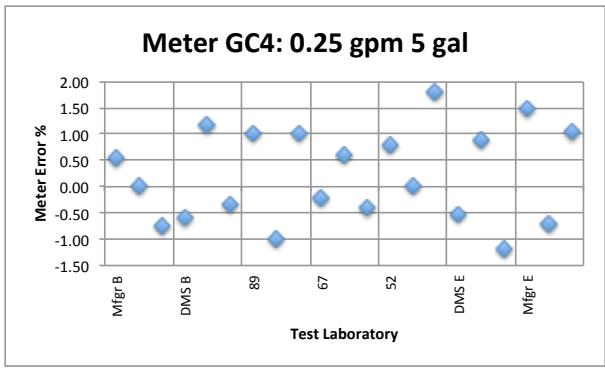
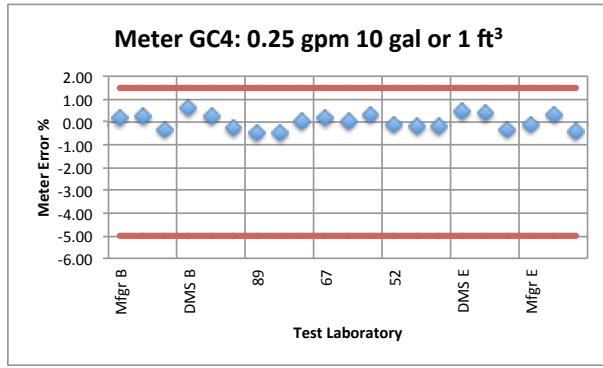
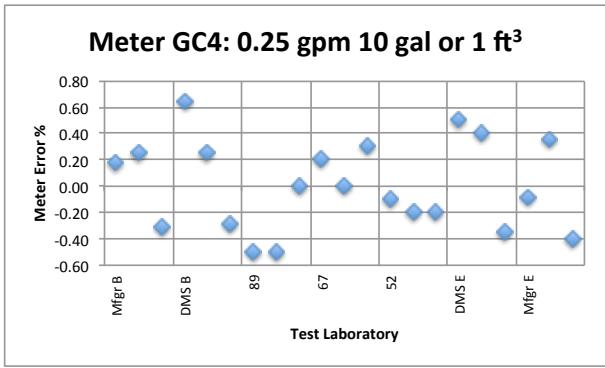
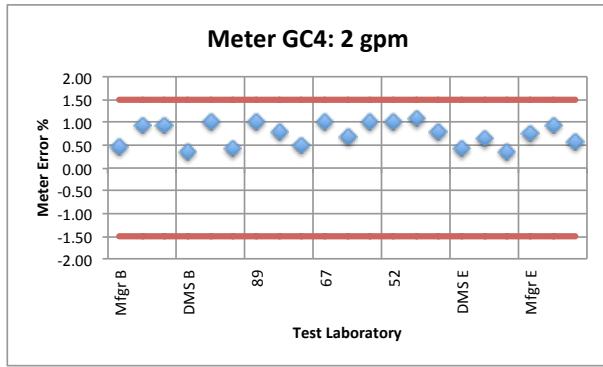
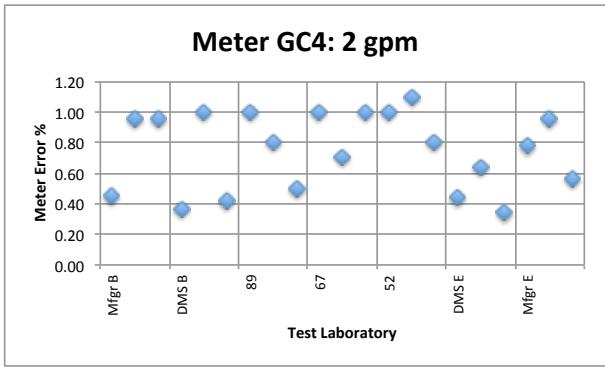
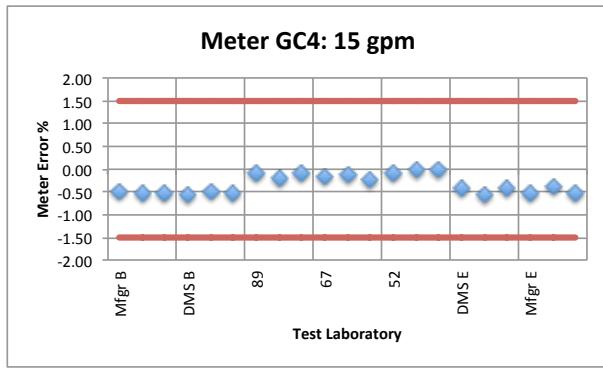
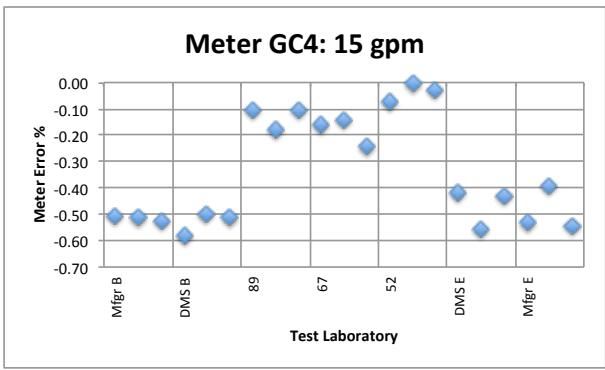


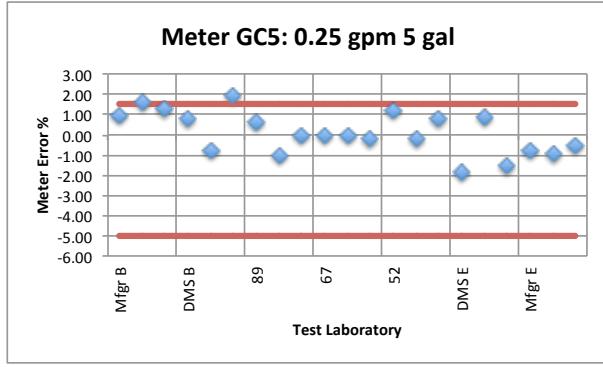
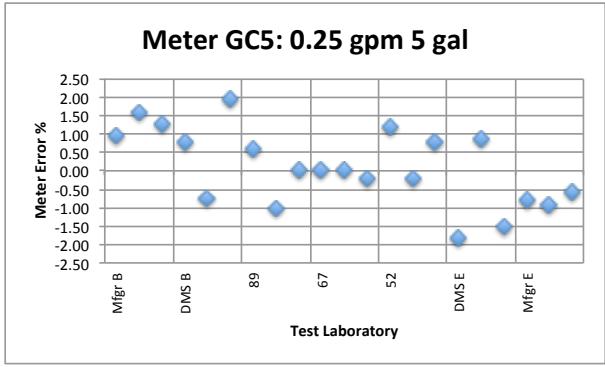
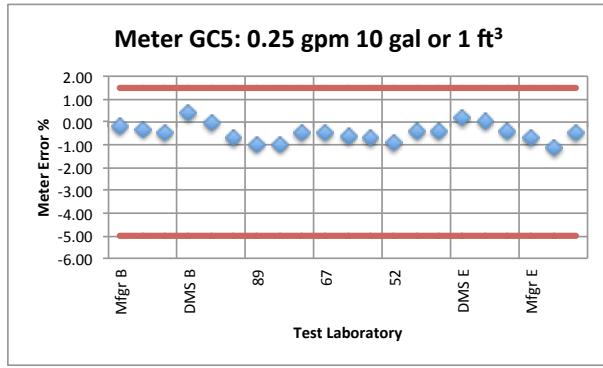
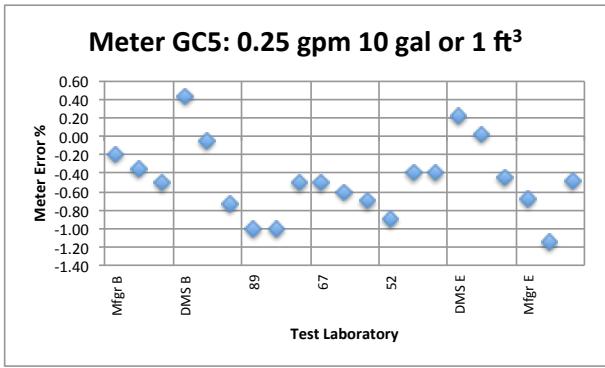
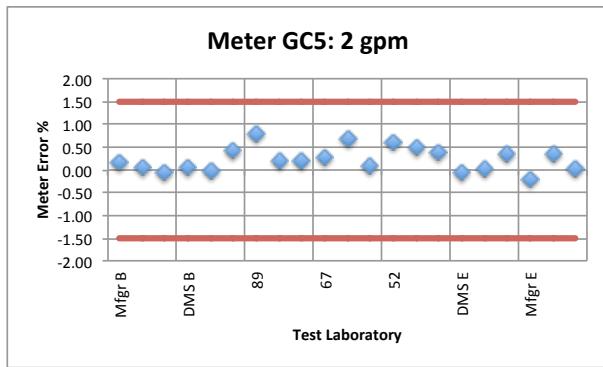
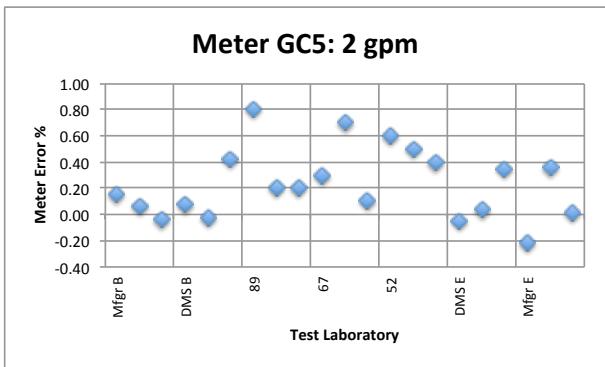
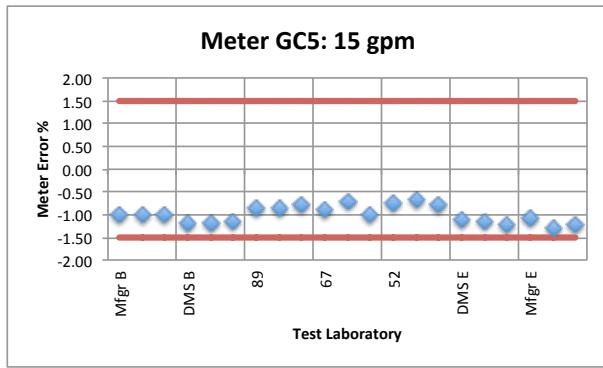
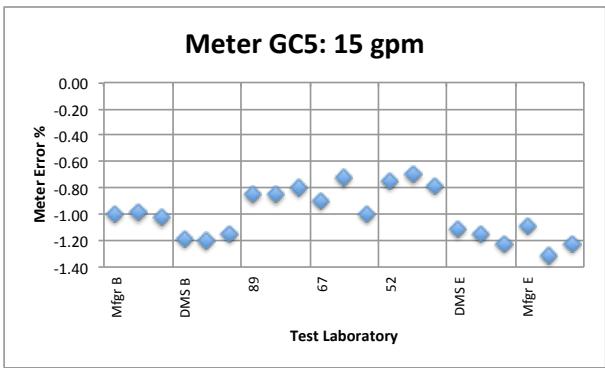


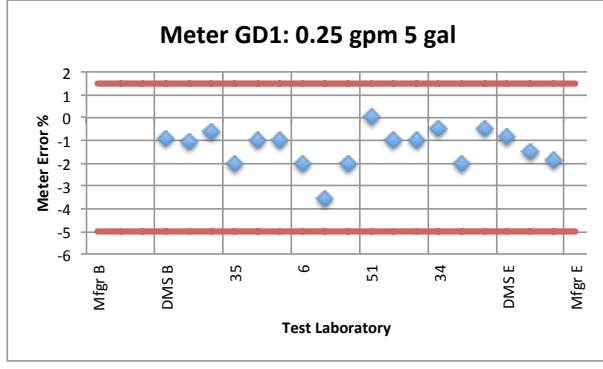
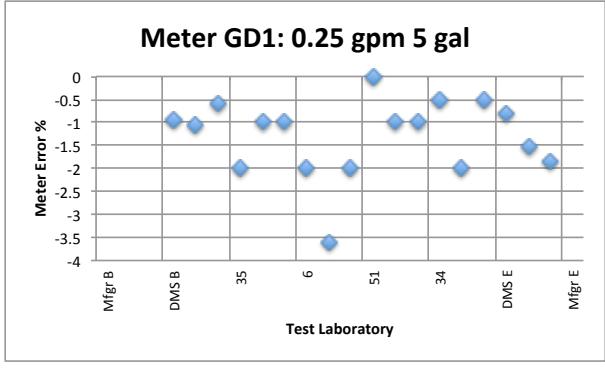
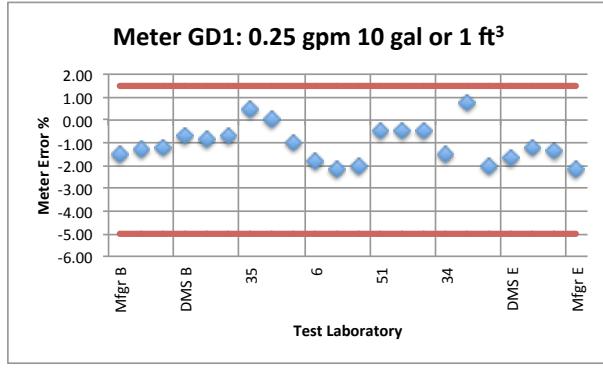
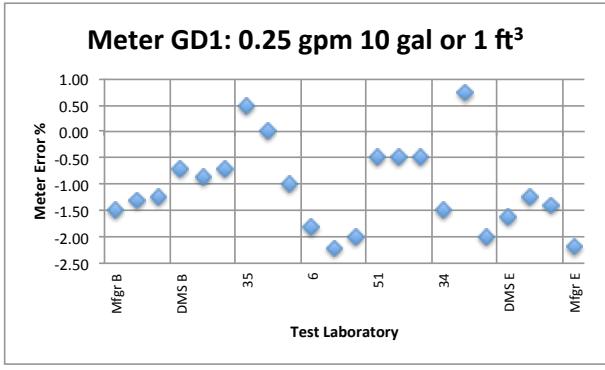
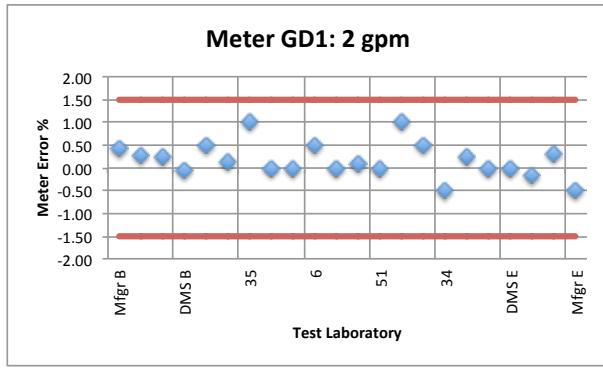
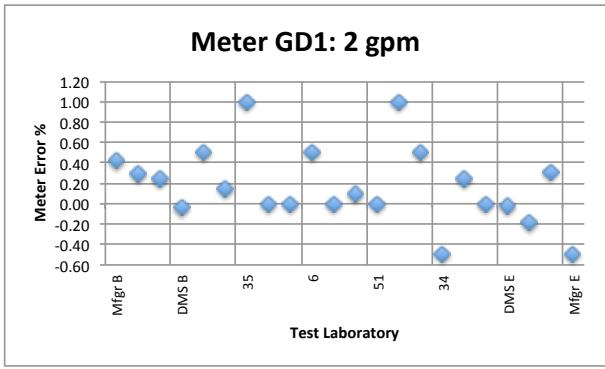
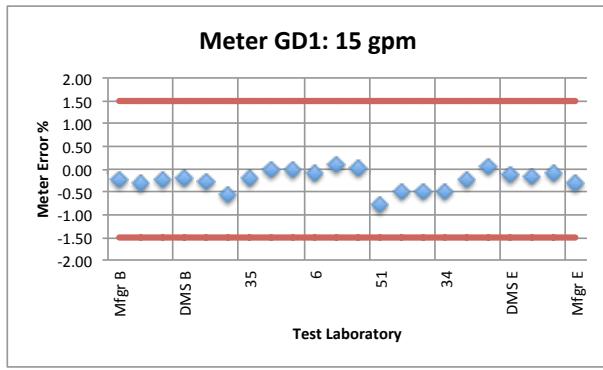
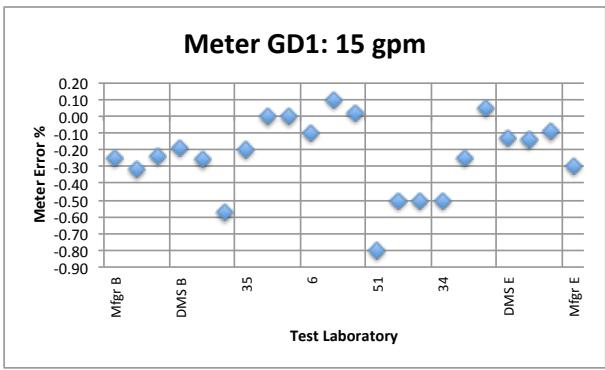


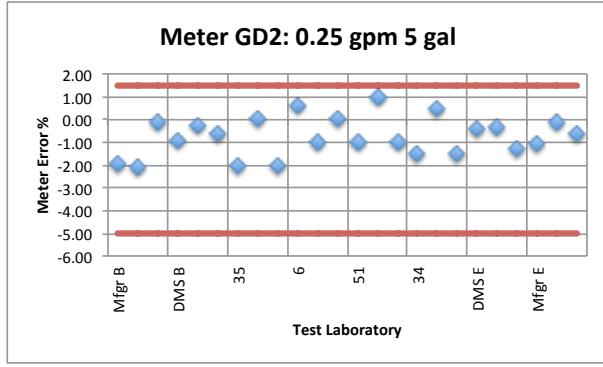
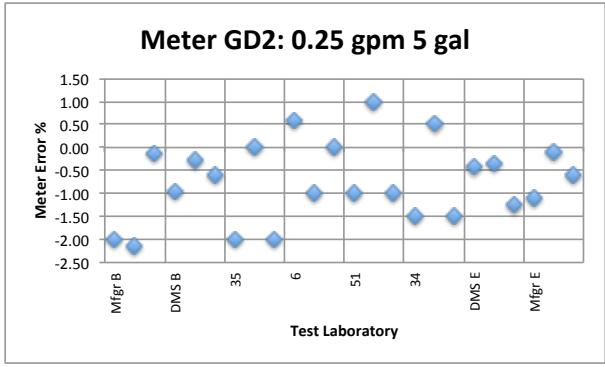
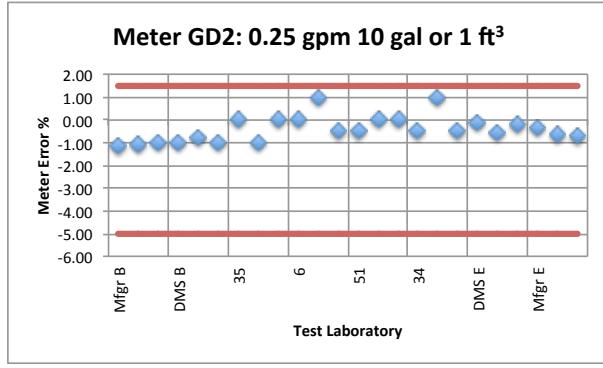
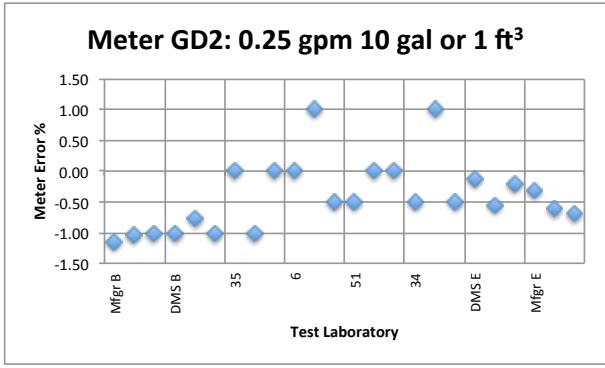
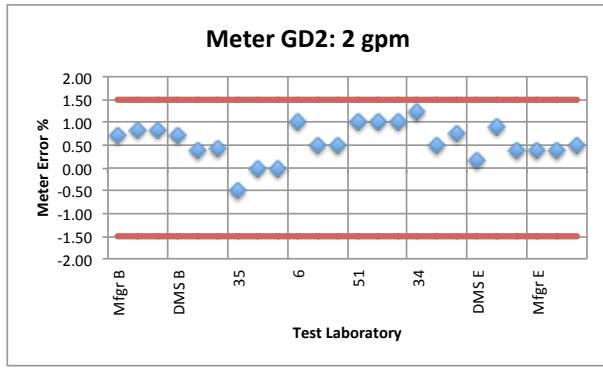
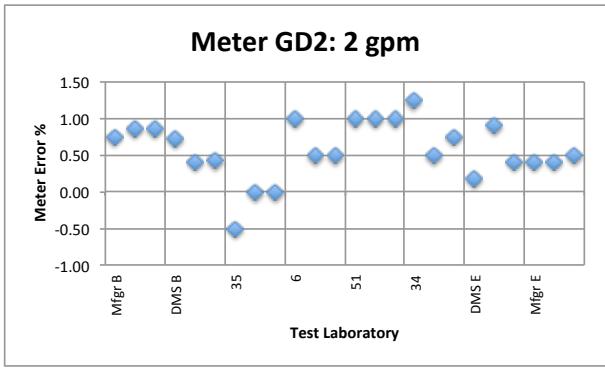
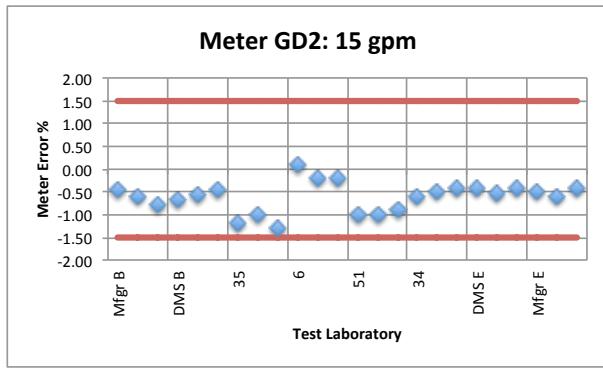
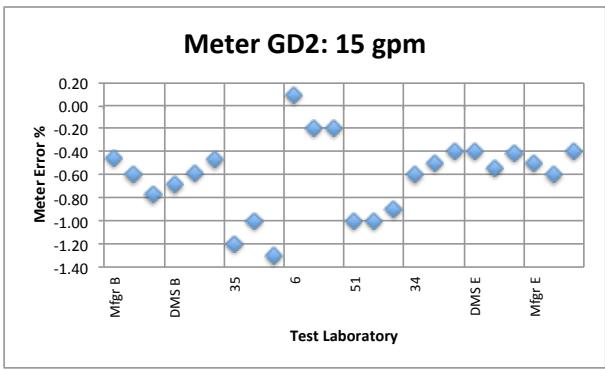


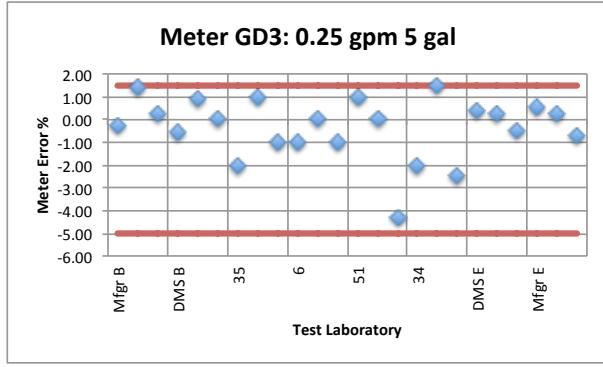
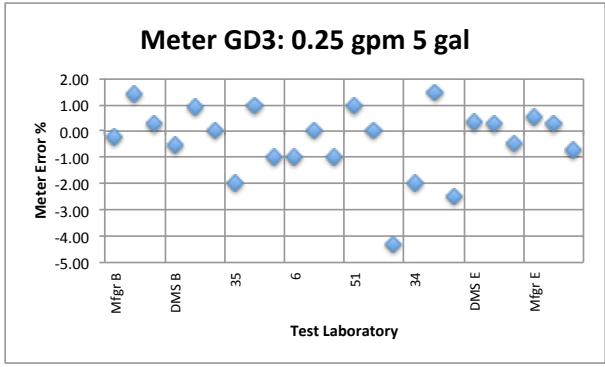
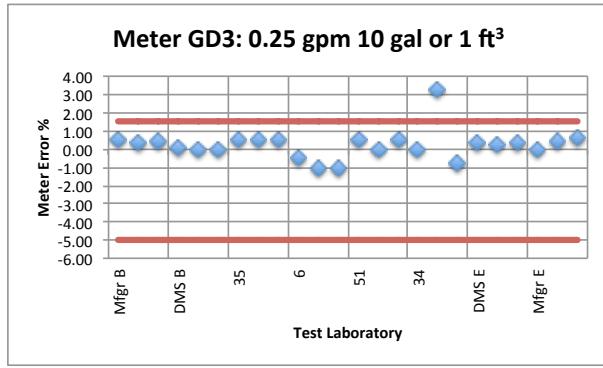
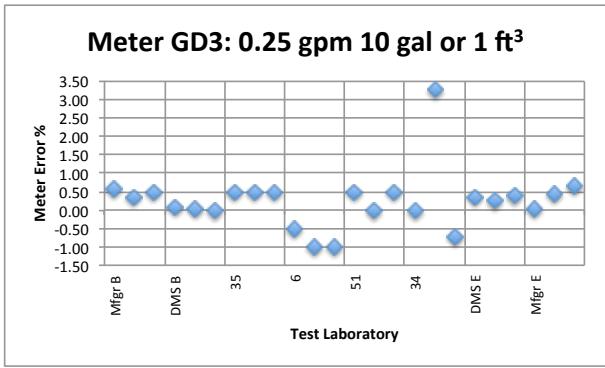
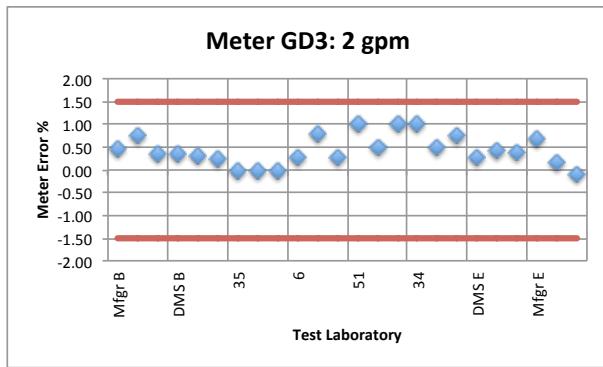
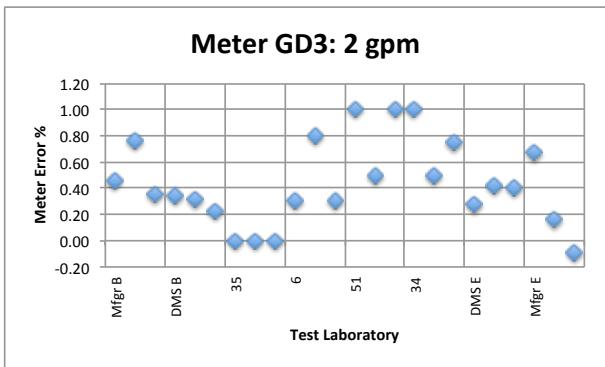
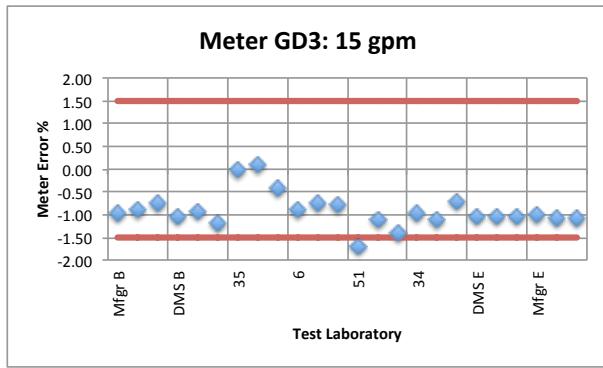
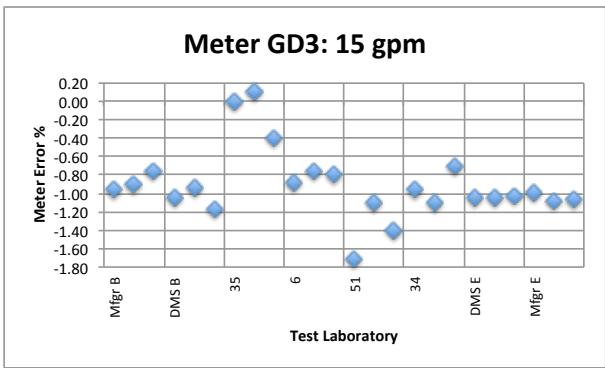


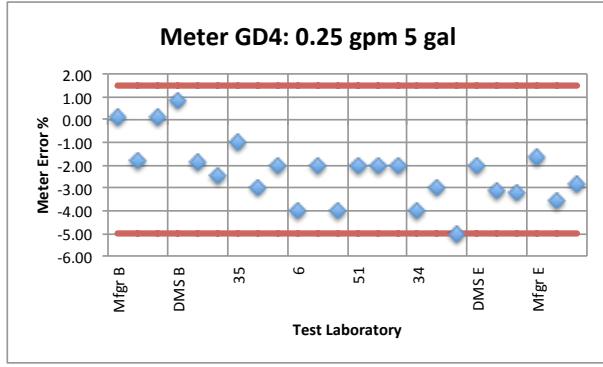
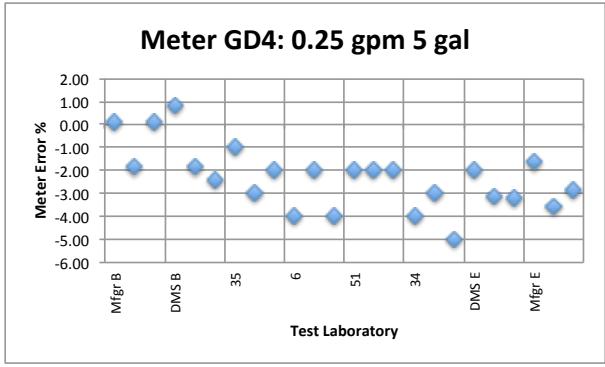
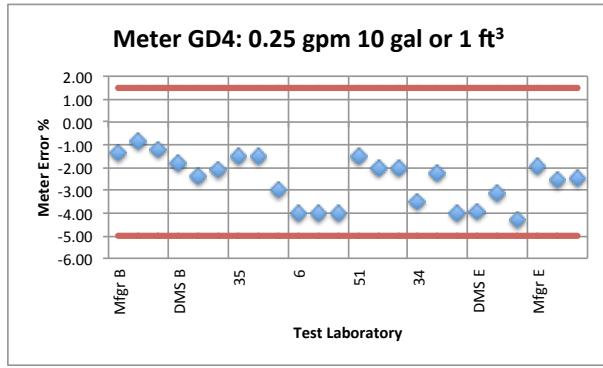
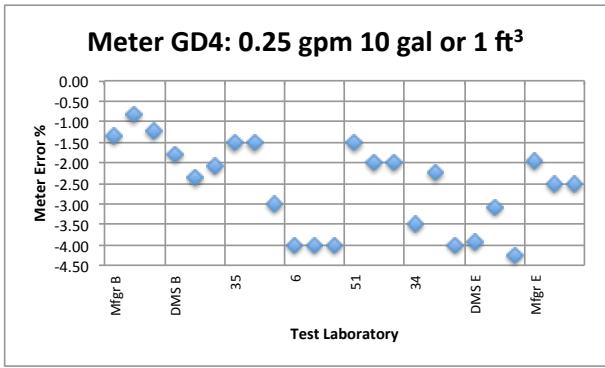
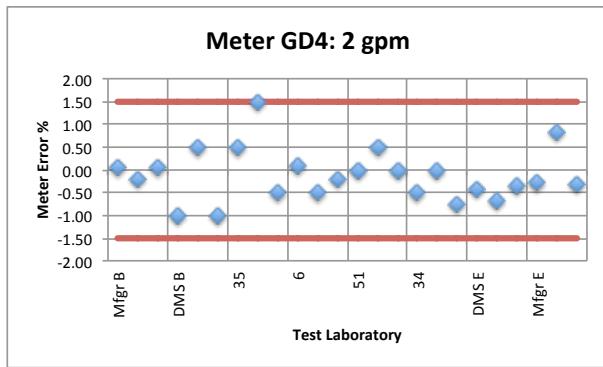
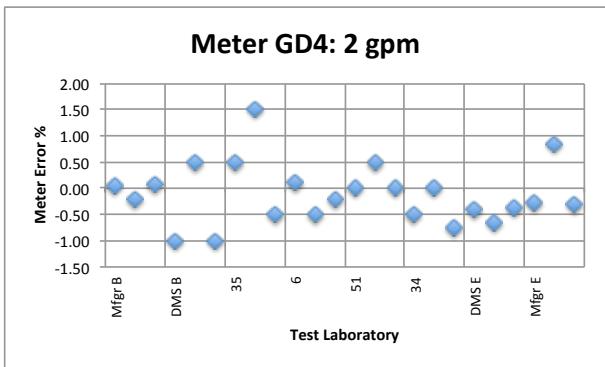
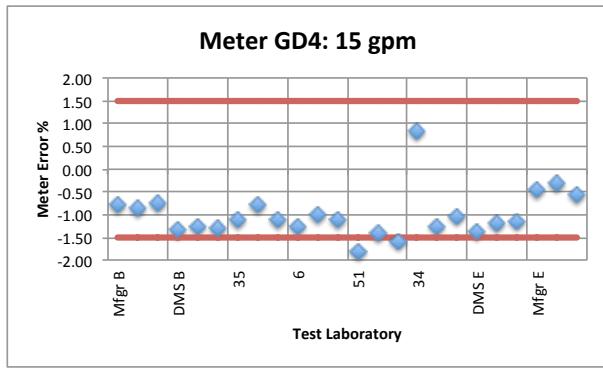
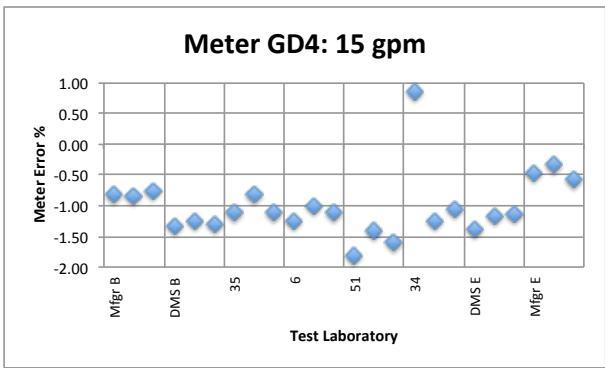


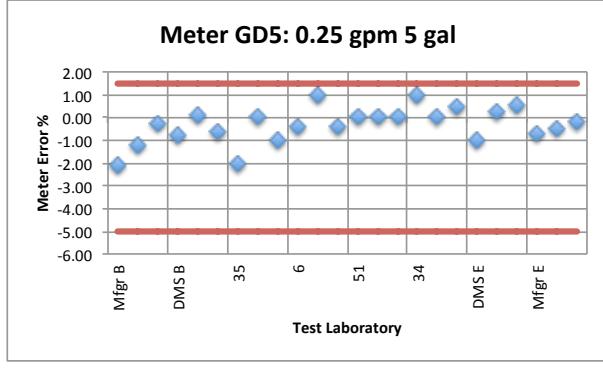
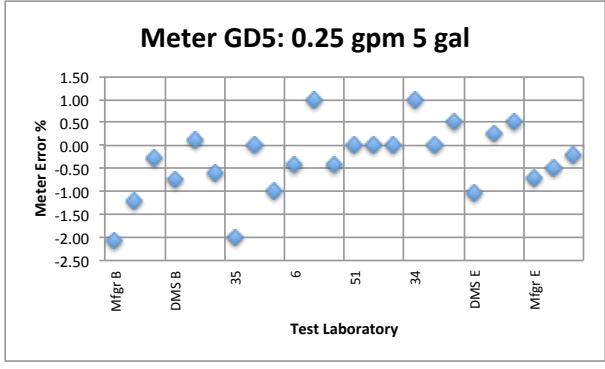
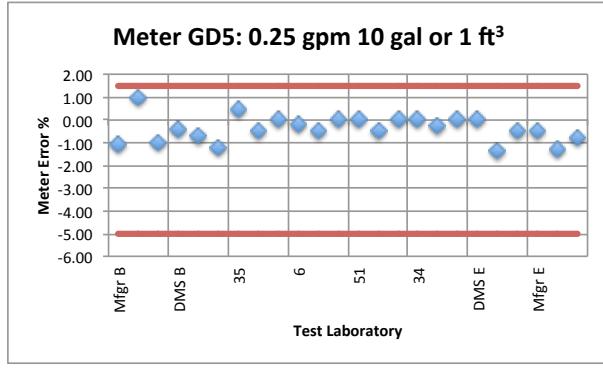
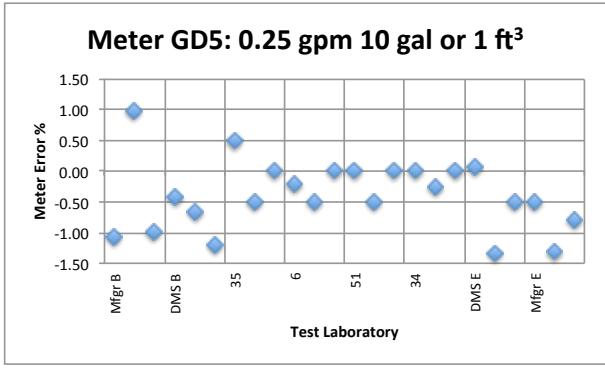
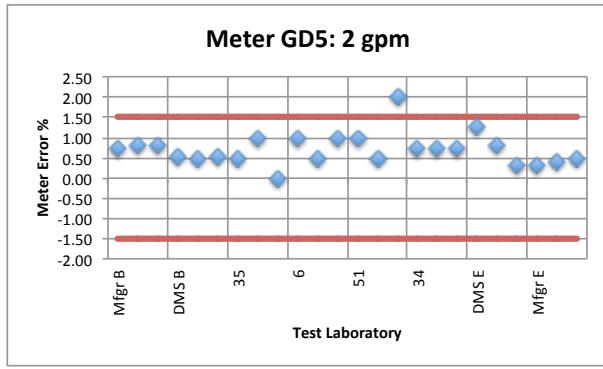
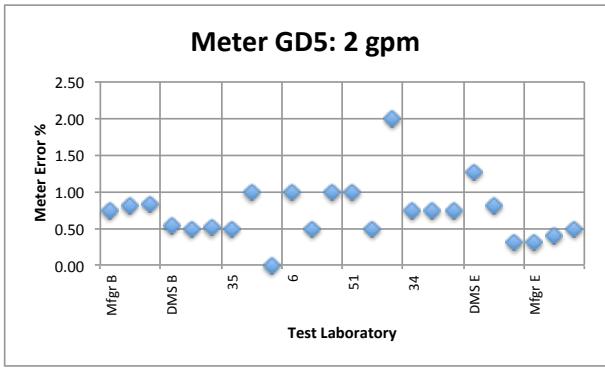
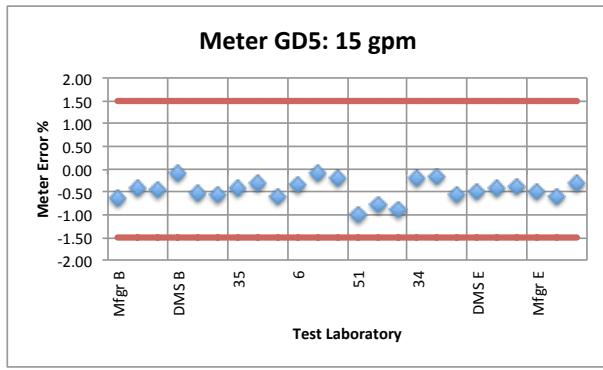
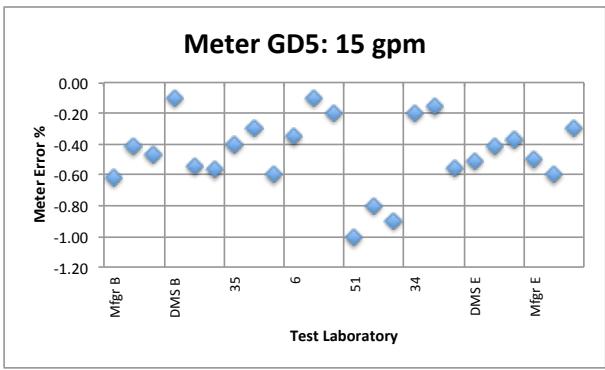












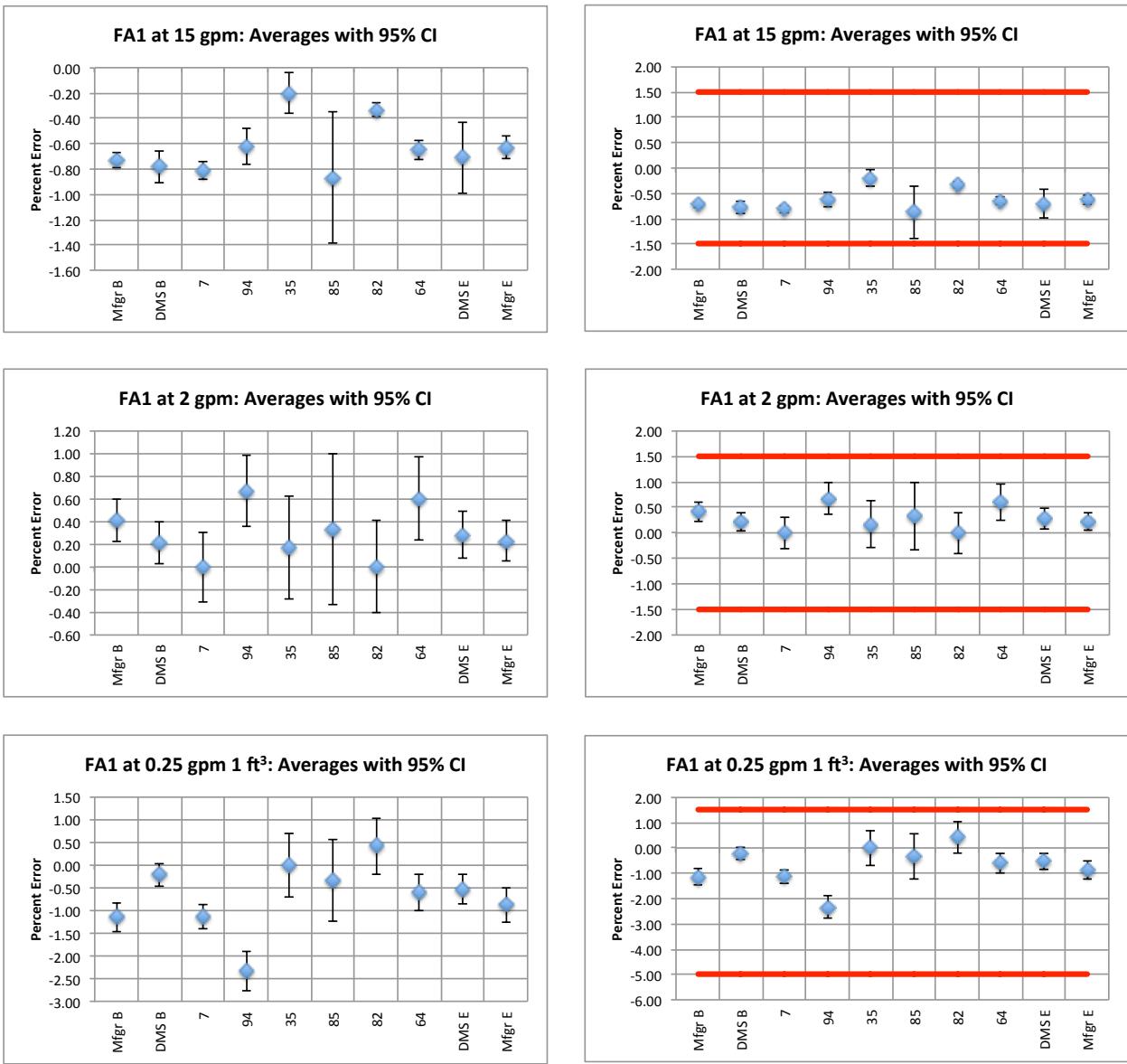
Average Errors and Error Bars

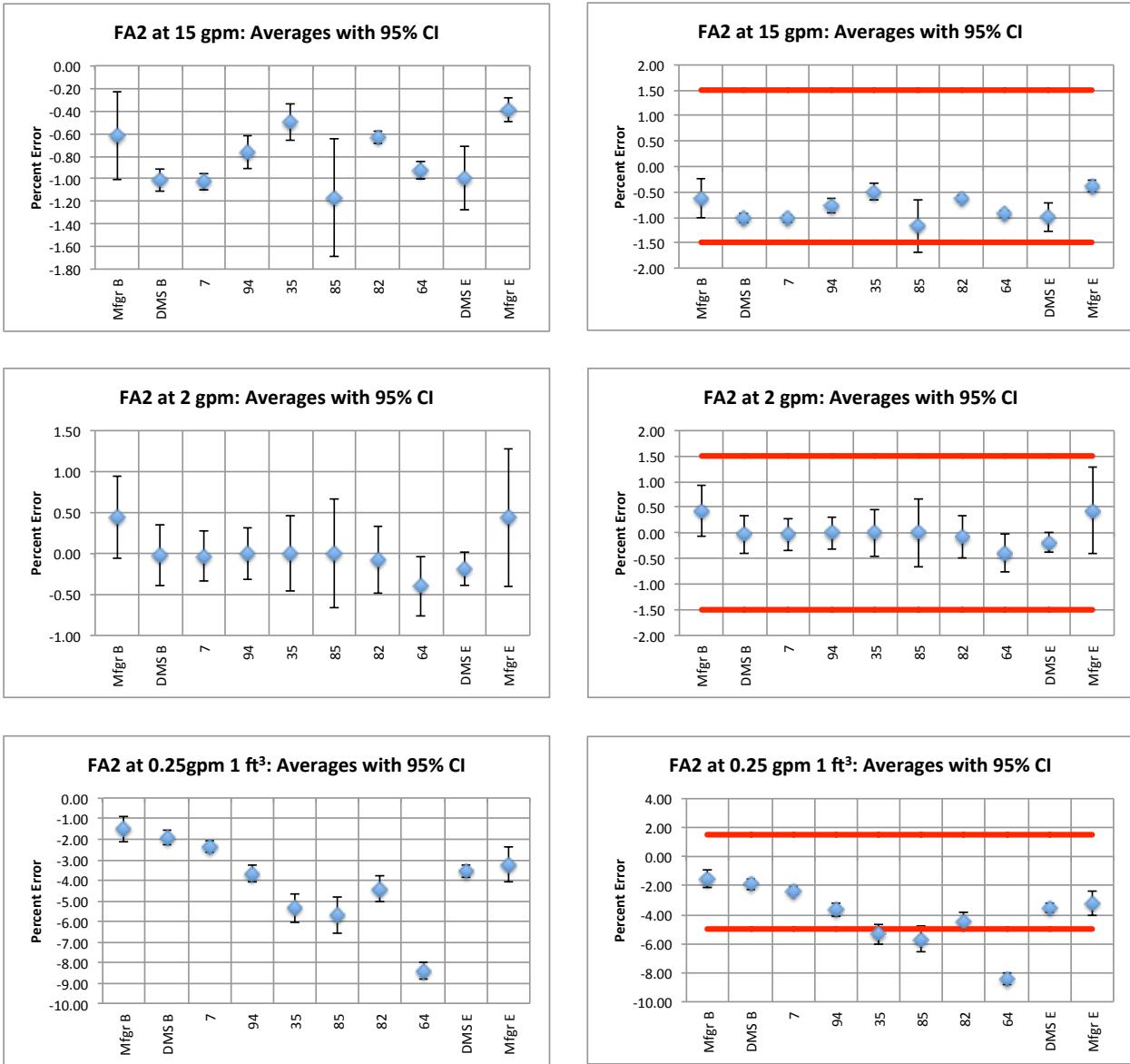
The following charts show the average meter error as determined by each laboratory with error bars that represent 95% confidence intervals based upon the pooled standard deviation for each laboratory at the respective flow rate. The standard deviations used for the error bars are based upon a limited amount of test data, so the standard deviations may not reflect the variations that may exist when a large number of meters are tested. The error bars provide a measure of whether or not the differences in the average meter errors are statistically significant, i.e., if the error bars do not overlap, then the differences are statistically significant at the 95% confidence level. The second chart plots the same information as the first chart, but includes the tolerance limits for the flow rate. This chart provides an indication of whether or not the differences from lab to lab are of practical significance relative to the tolerances.

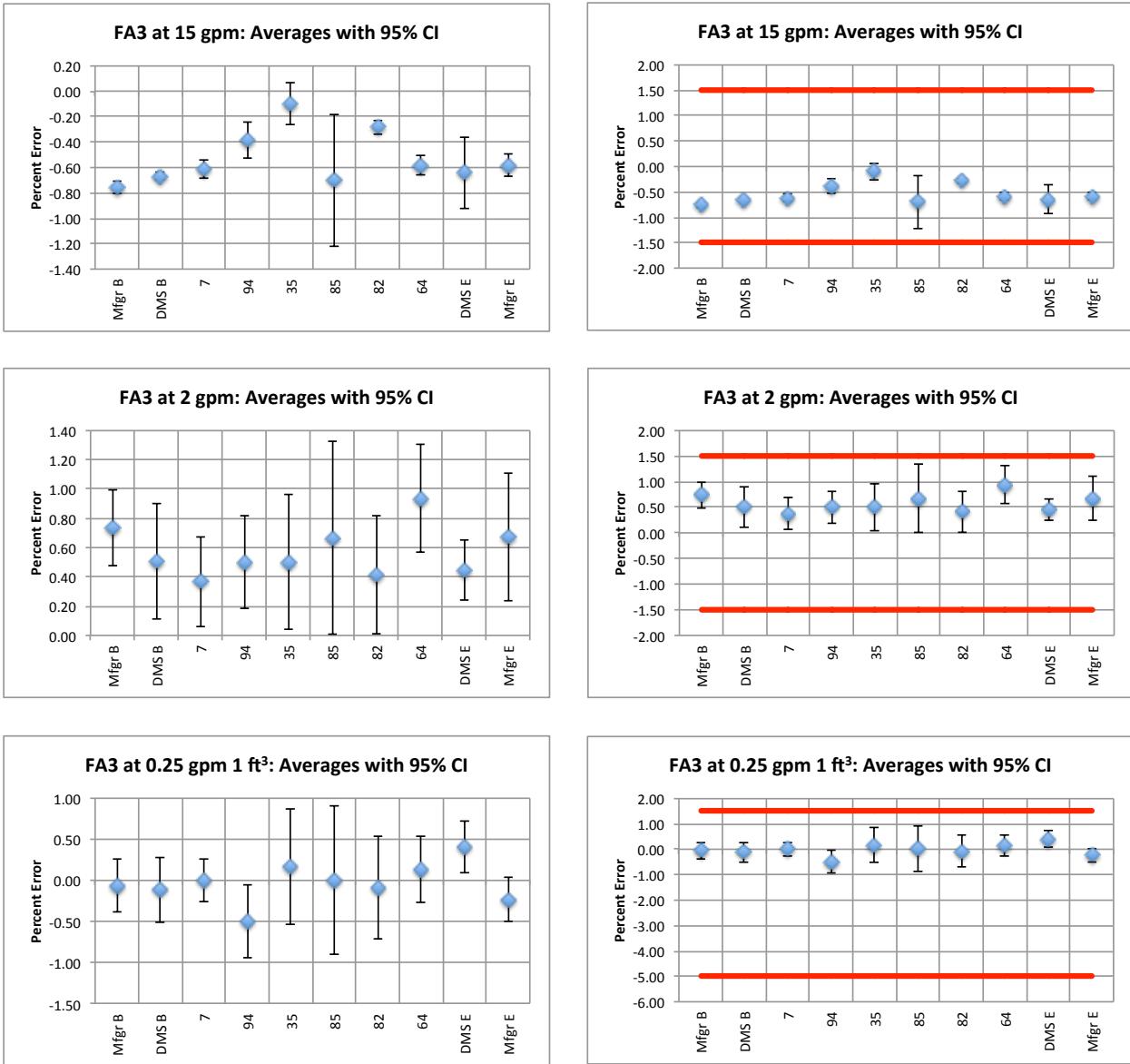
Pooled standard deviations were computed for each manufacturer lab and DMS for the individual test results for each group of meters for each flow rate and size of test draft. Each pooled standard deviation for each flow rate and size of test draft for each manufacturer and DMS at the beginning and end of the survey was used to compute the 95% confidence level error bars for the average results at the beginning and the end for each meter for each lab.

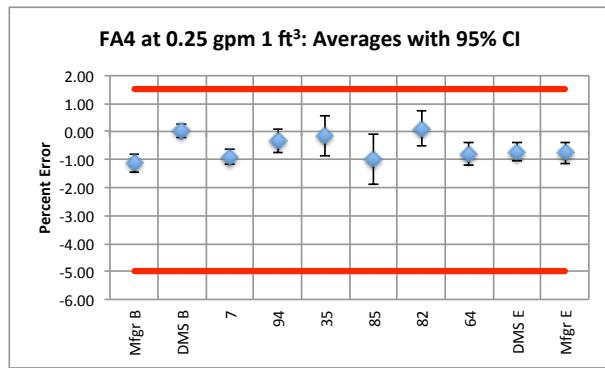
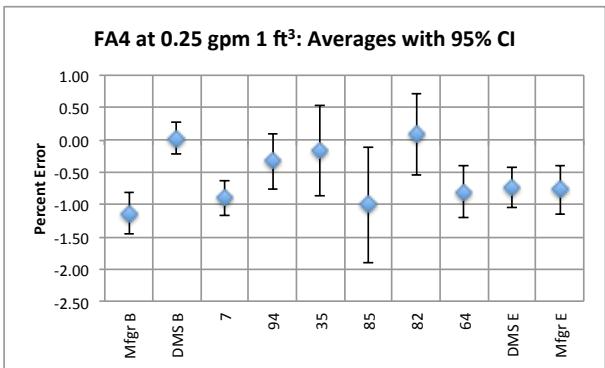
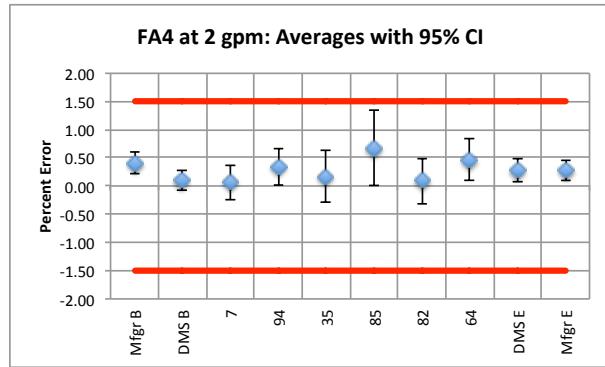
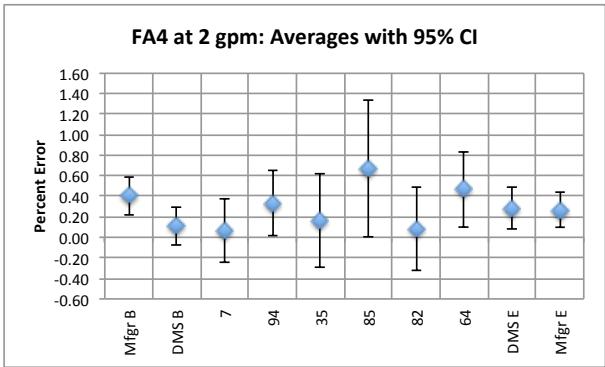
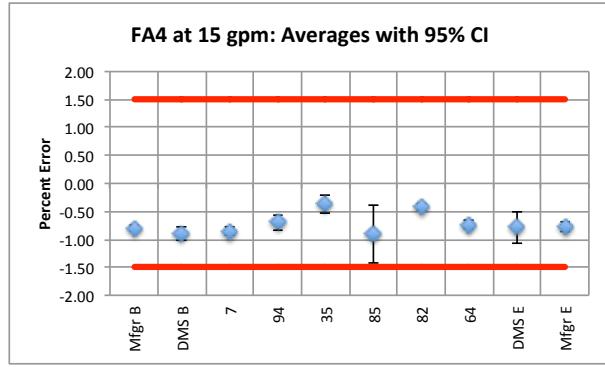
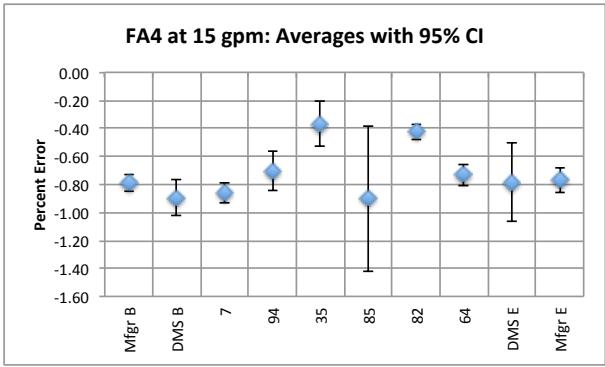
A change in meter accuracy over the length of the study can be detected by any upward or downward trends in the test results.

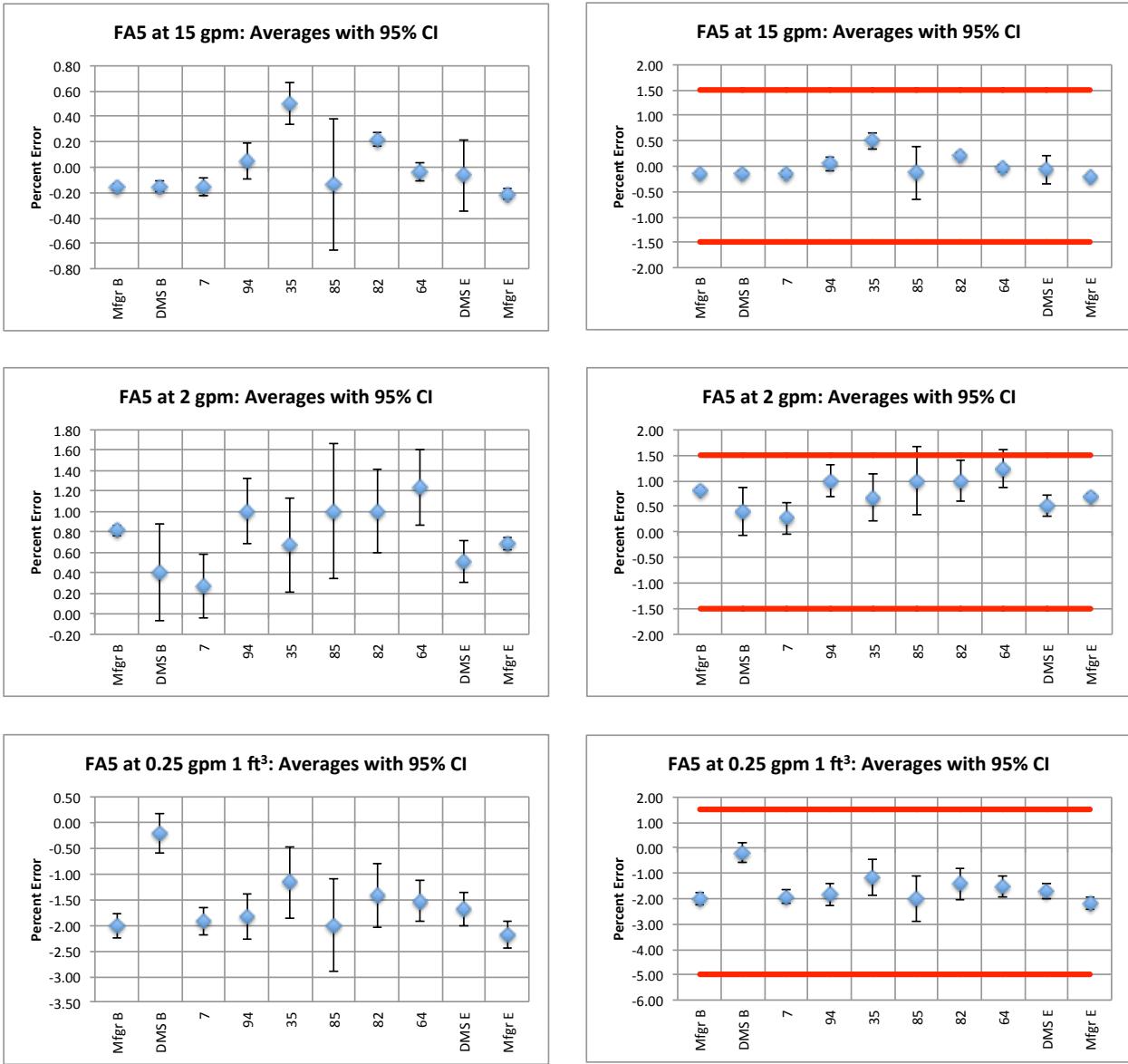
An overall evaluation of the test results can be obtained by examining the test results for each meter as tested in sequence by each laboratory. For meters indicating in gallons, the results for the different test draft sizes of 10 gal and 5 gal are shown on separate charts. Each manufacturer tested its own meters at the beginning and the end of the survey. The manufacturer's results at the beginning and end of the survey are identified as Mfgr B and Mfgr E, respectively. The same codes are used for all manufacturers, but each manufacturer can identify its meters by the meter identification in the titles of the charts. The California Division of Measurement Standards tested all of the meters at the beginning and end of the survey. The DMS results at the beginning and end of the survey (i.e., before and after the county tests) are identified as DMS B and DMS E, respectively. The codes for the counties that tested the specific meter are shown in the labels for the X-axis.

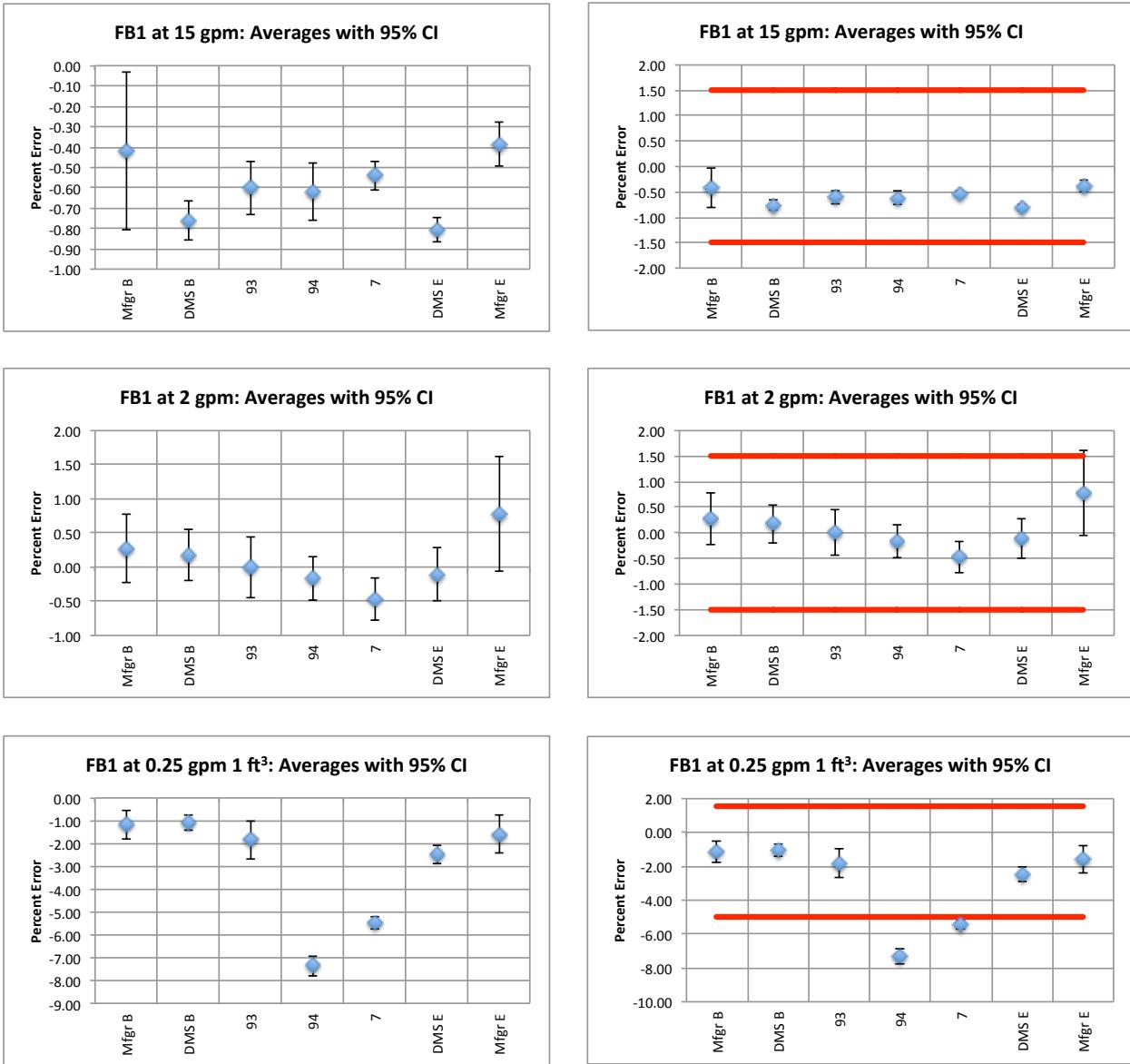


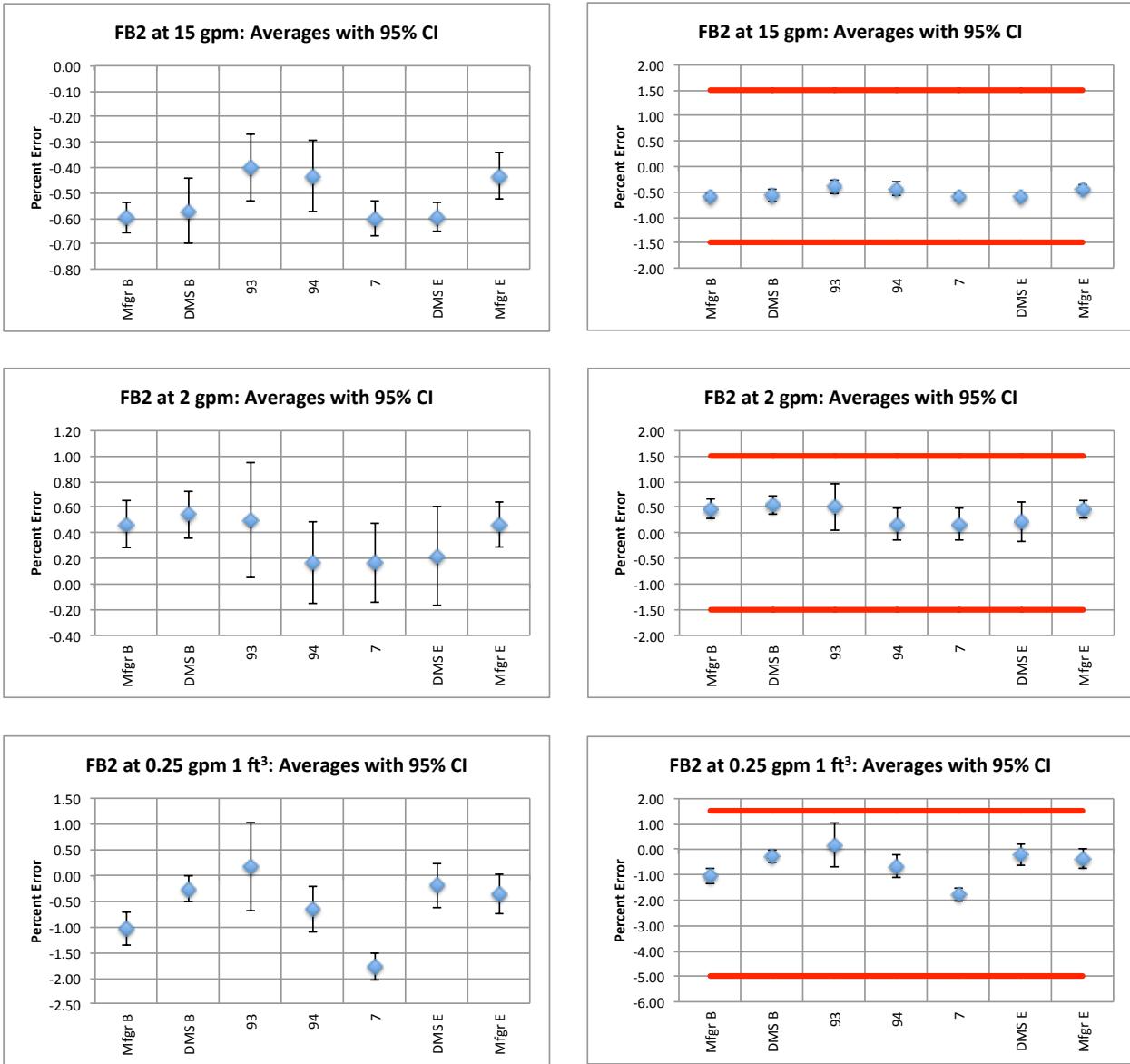


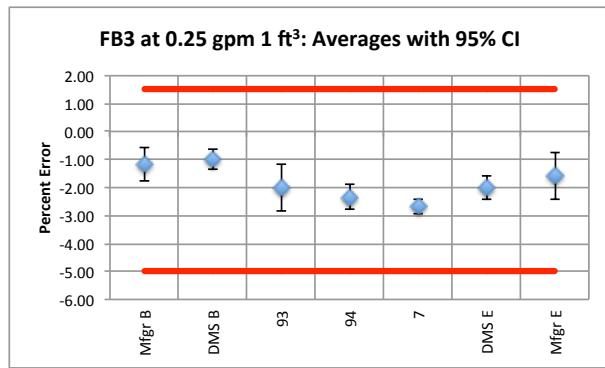
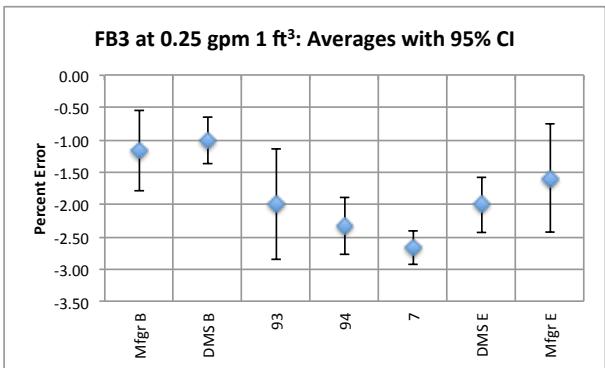
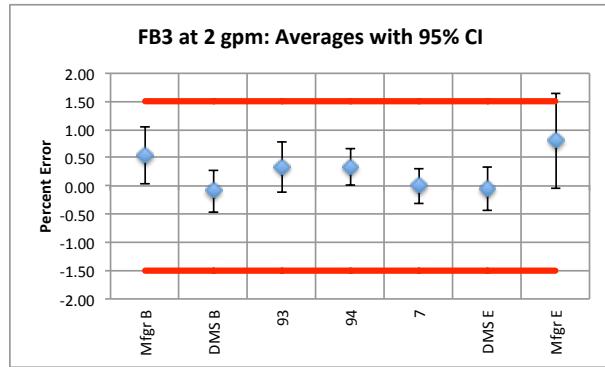
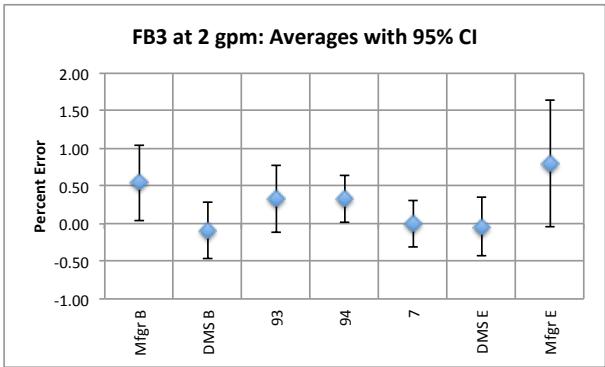
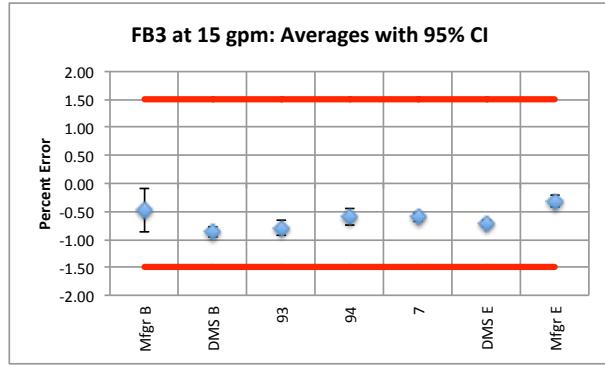
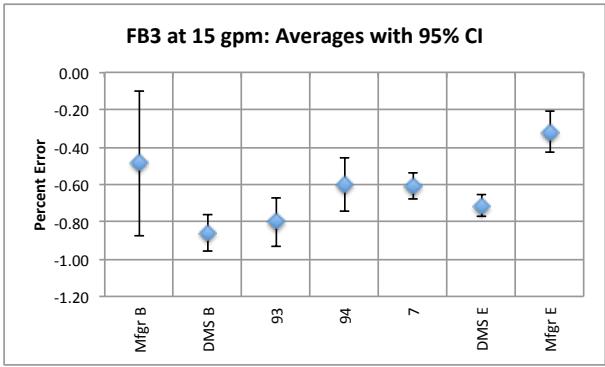


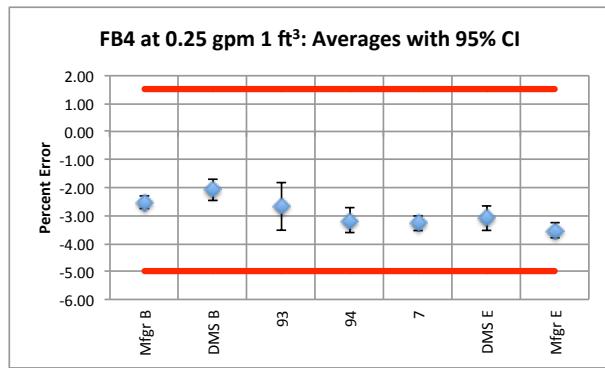
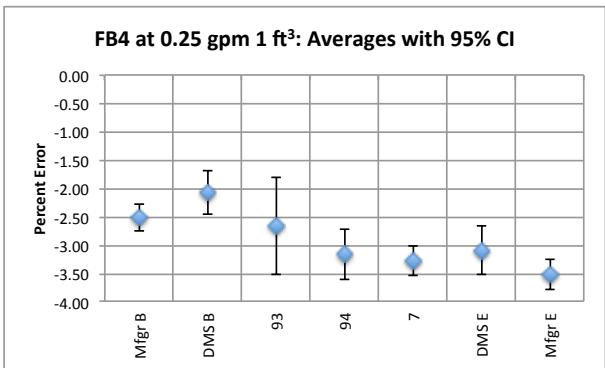
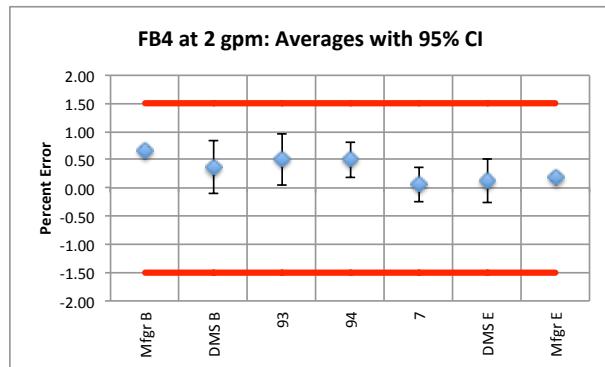
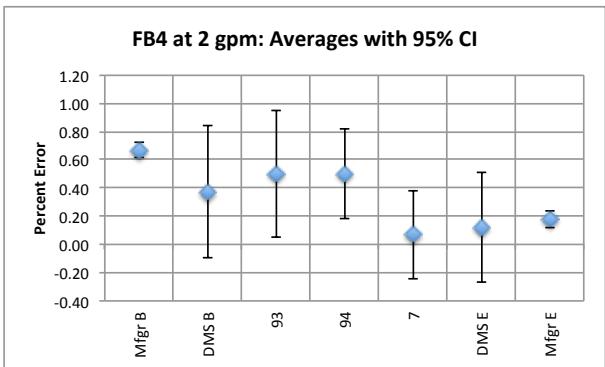
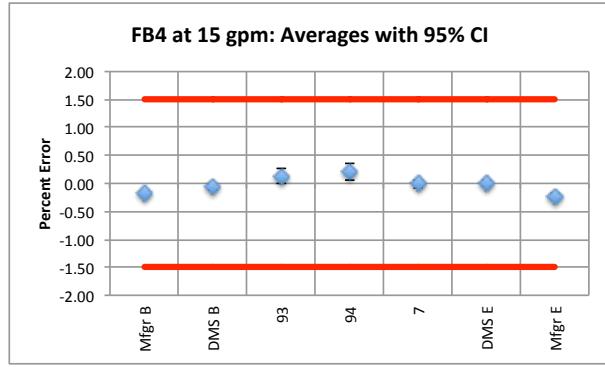
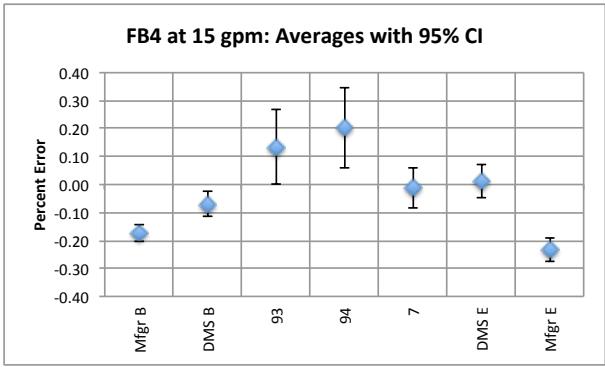


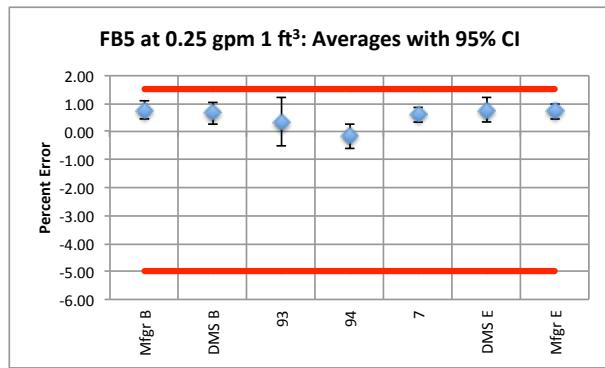
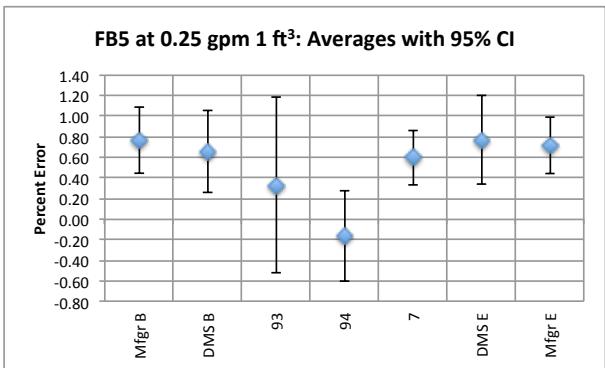
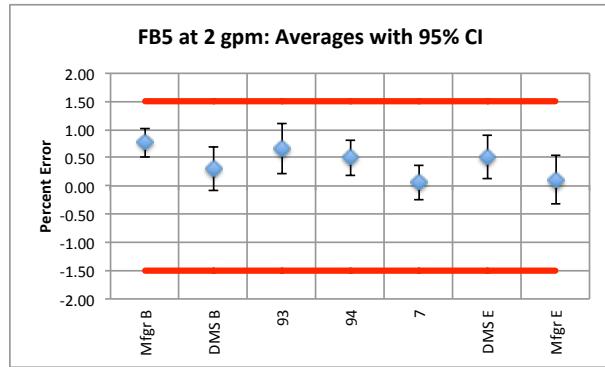
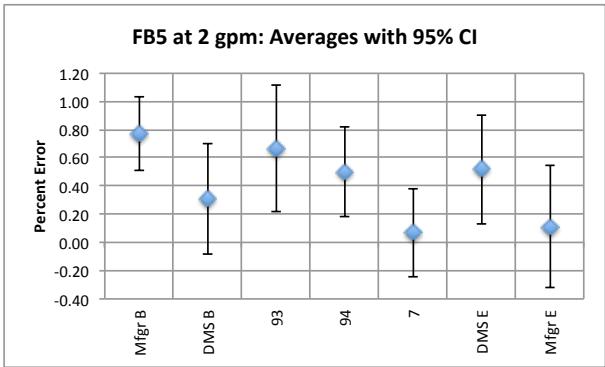
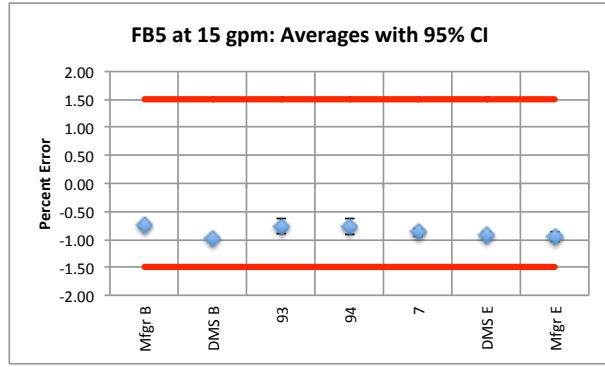
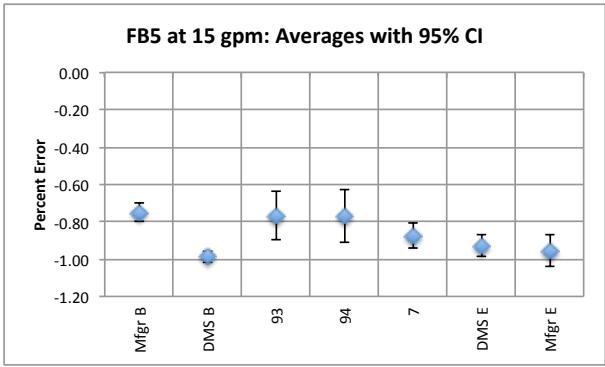


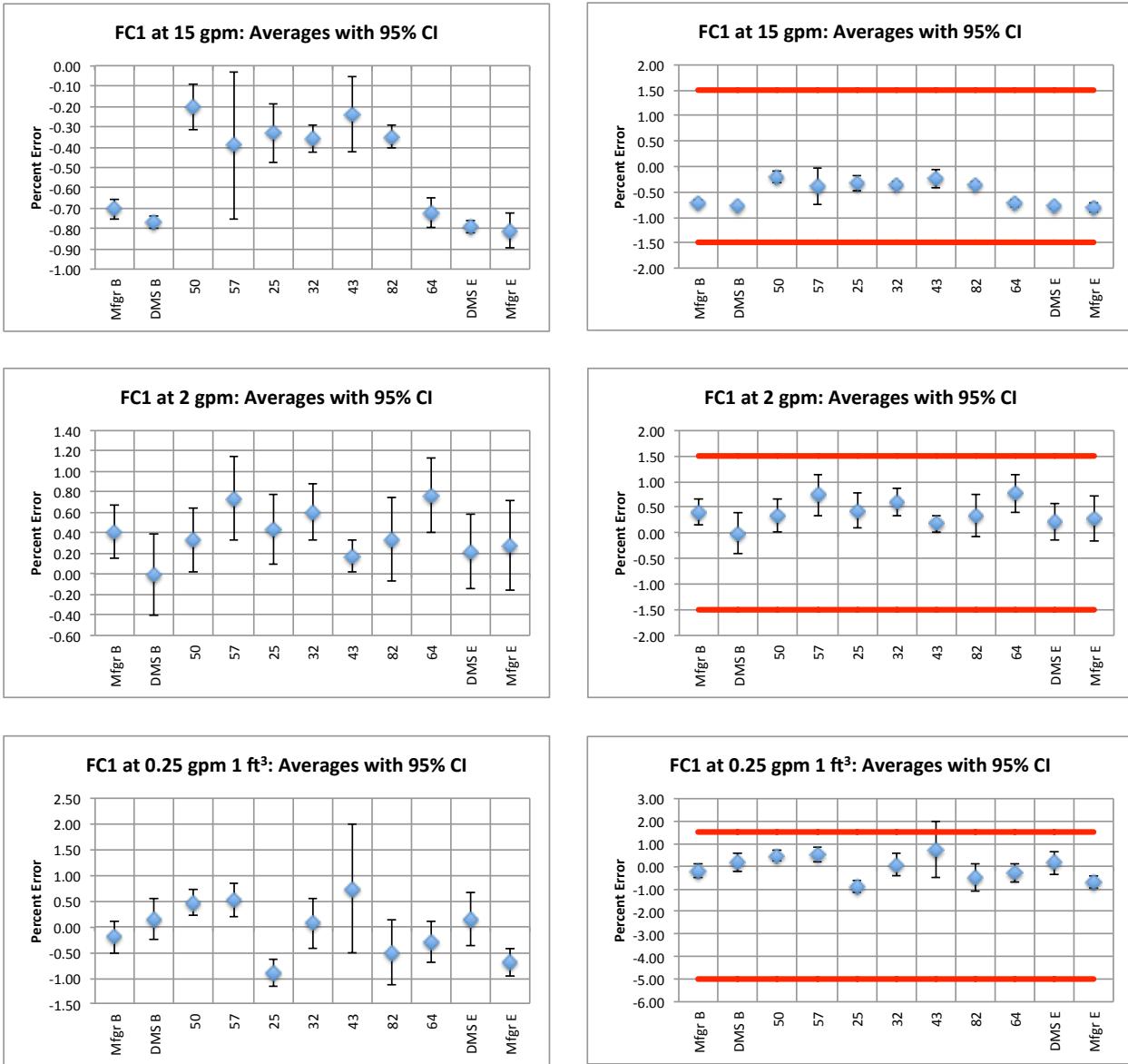


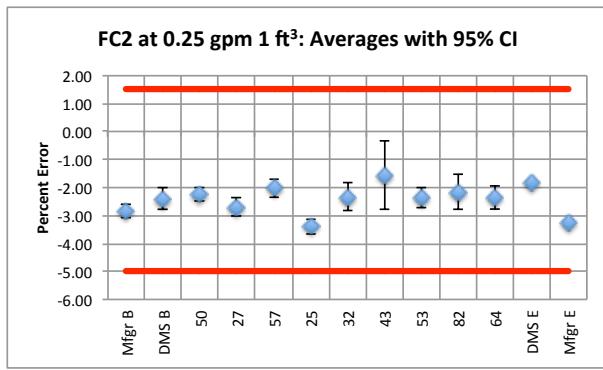
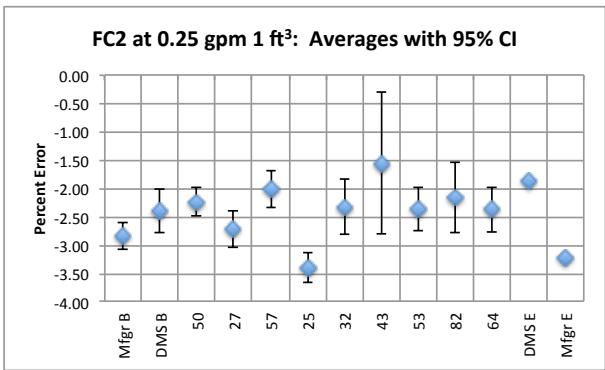
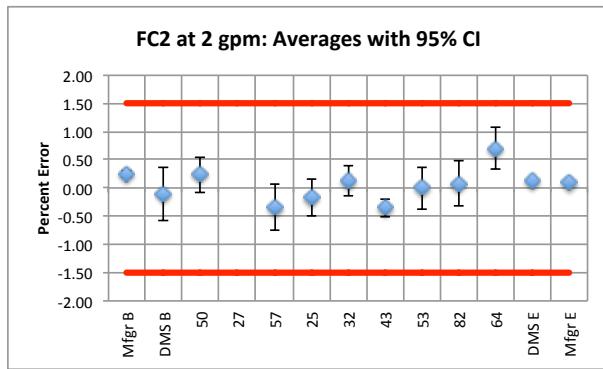
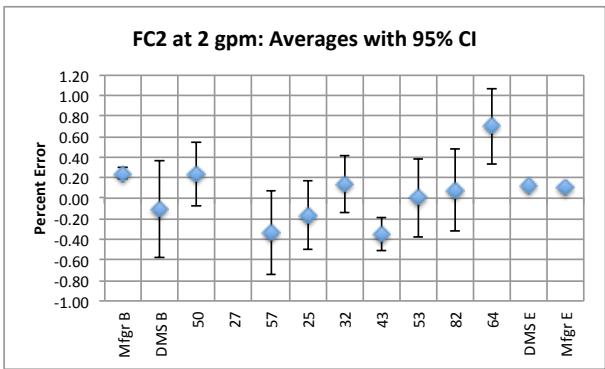
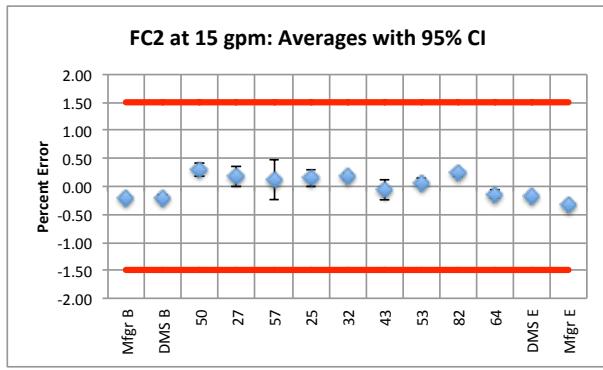
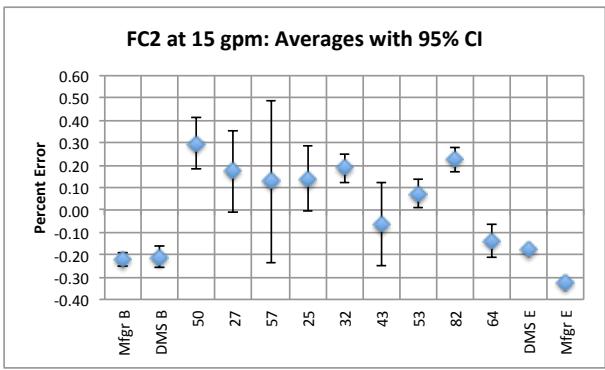


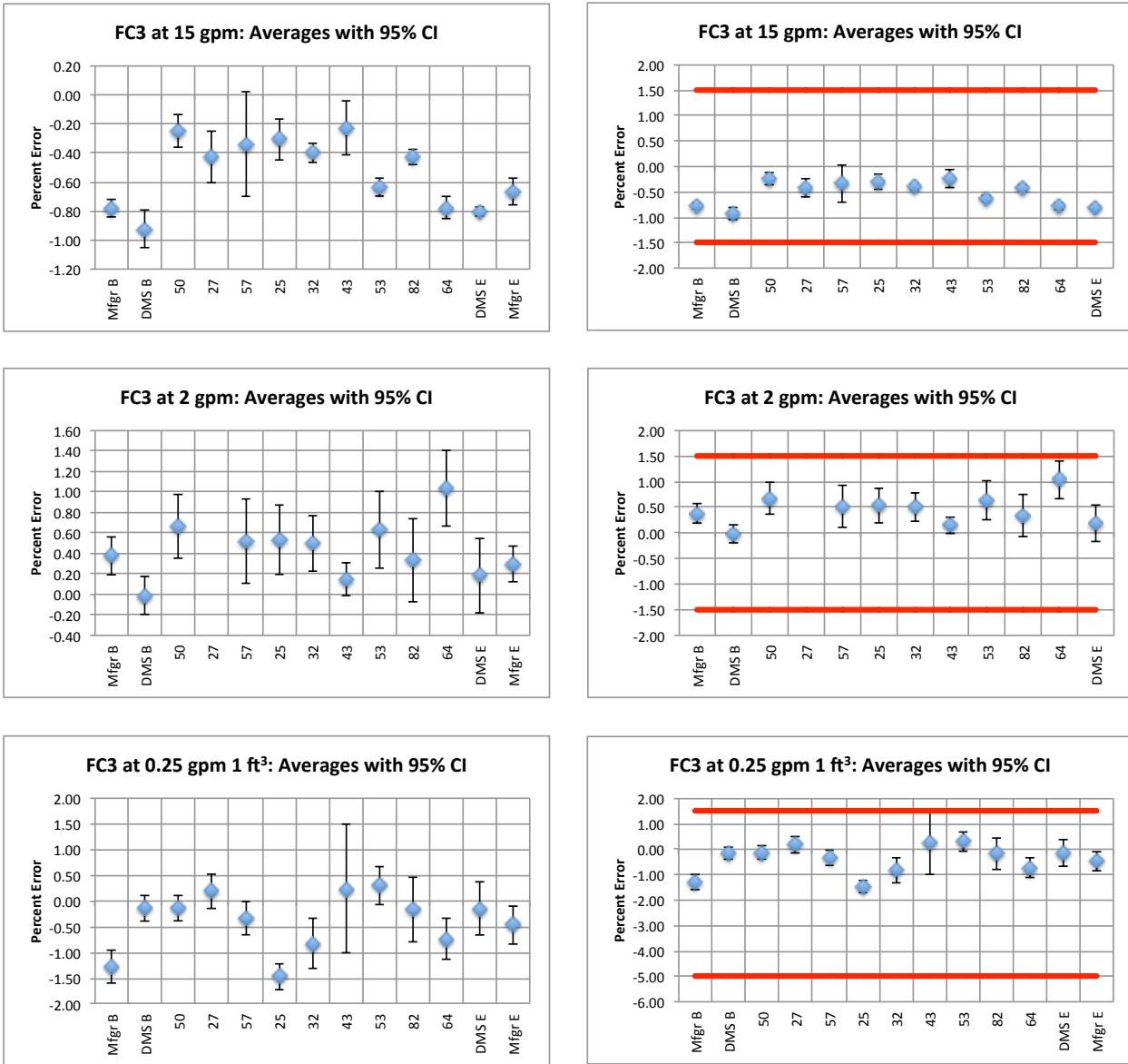


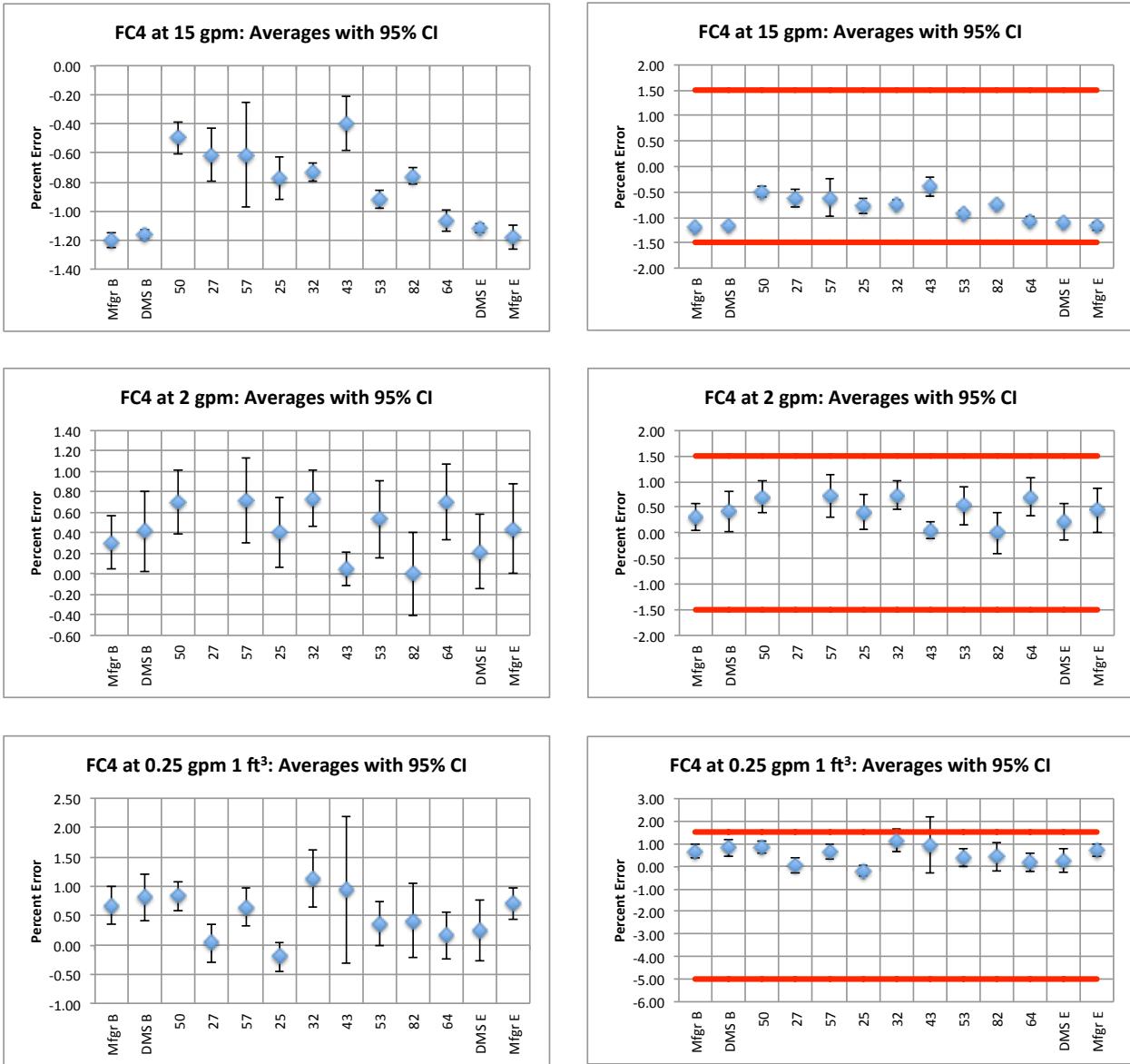


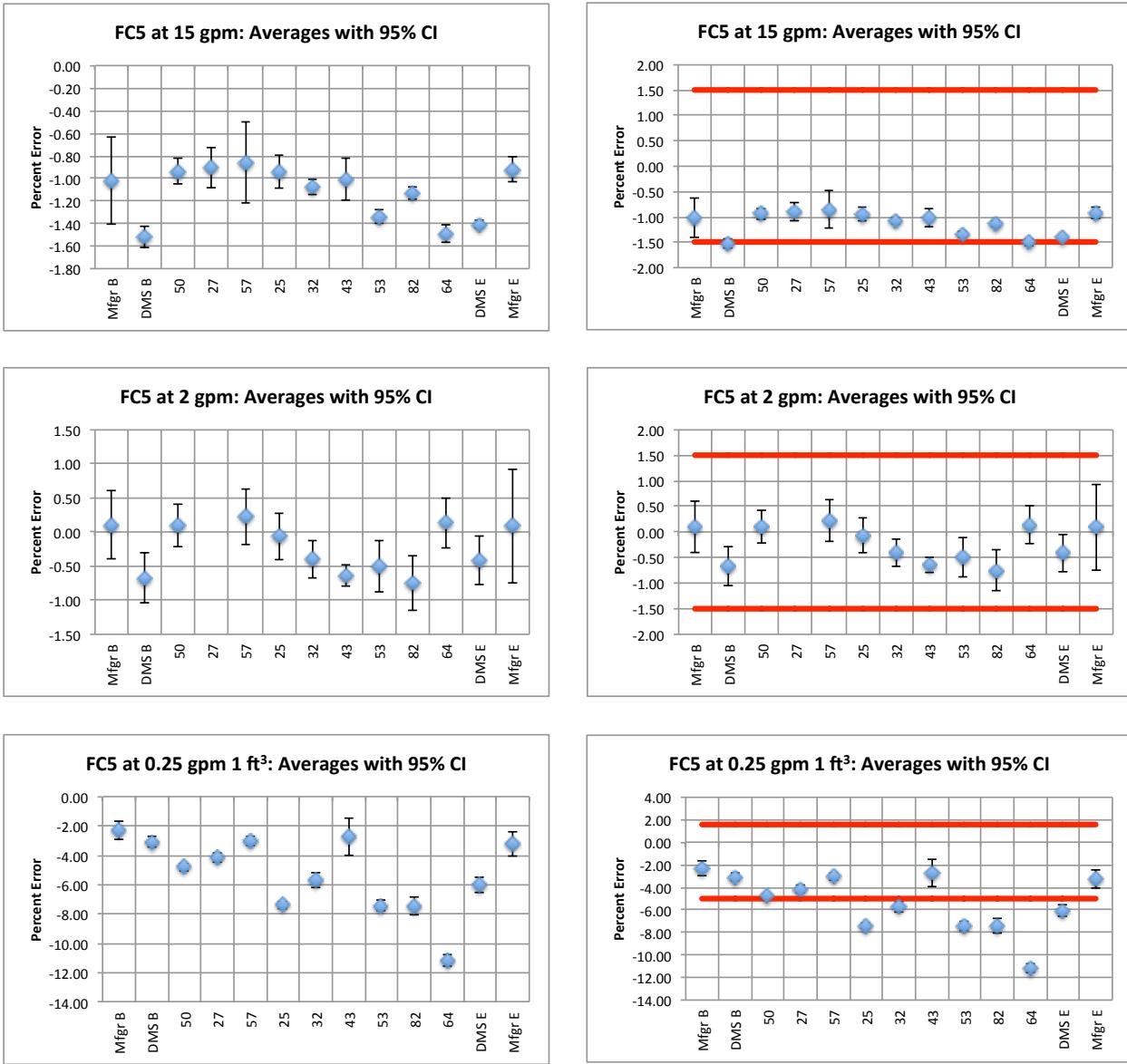


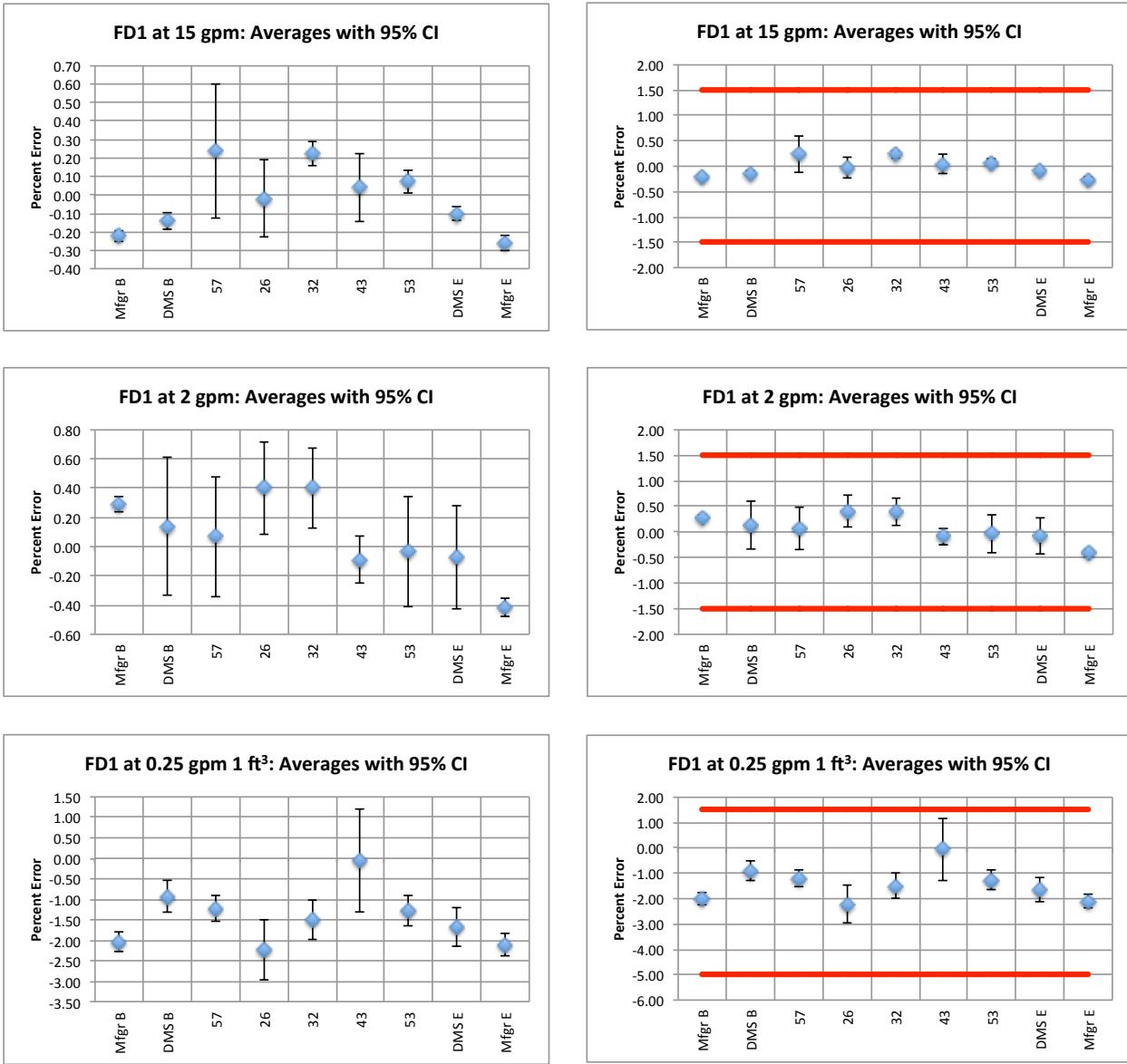


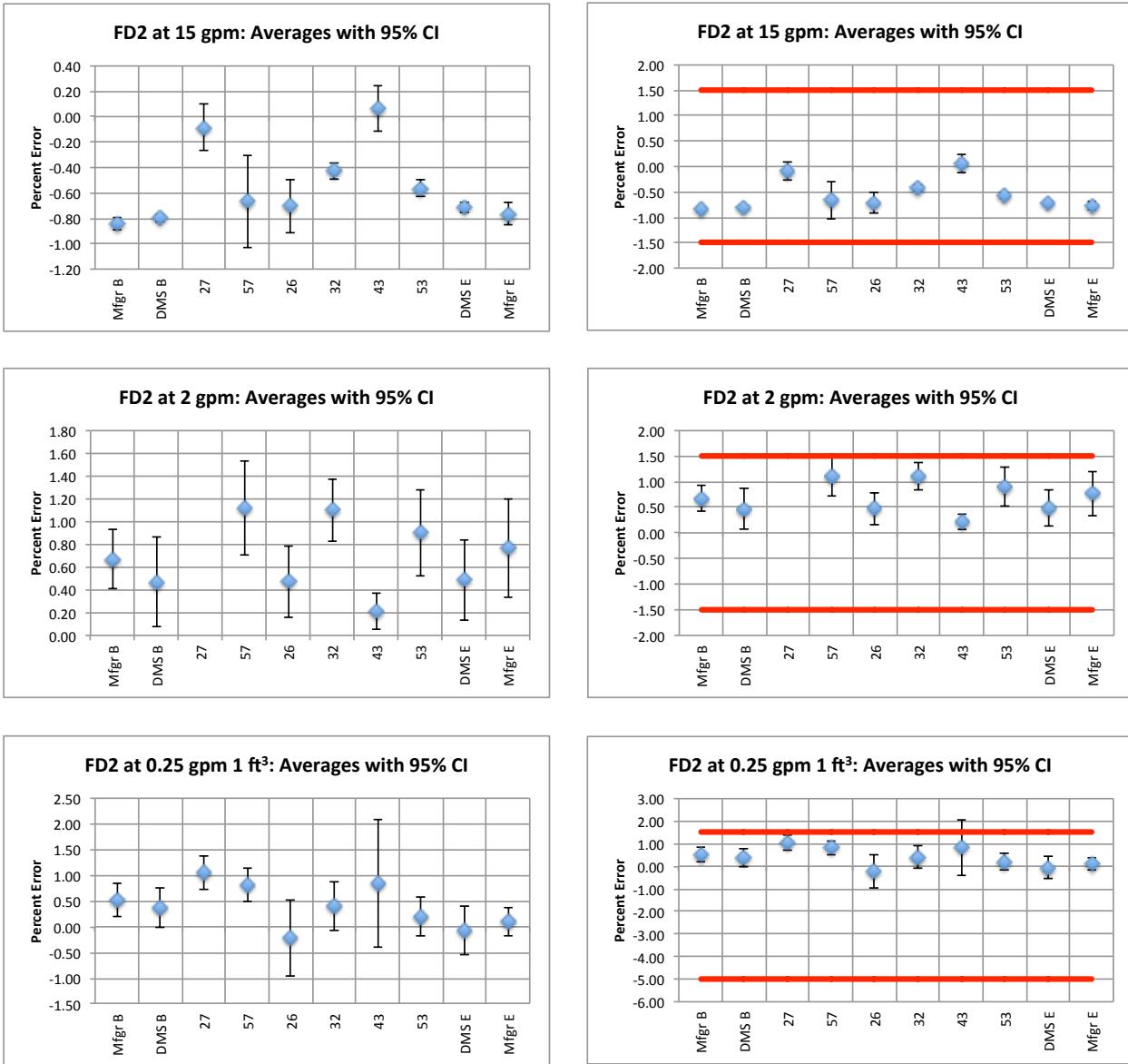


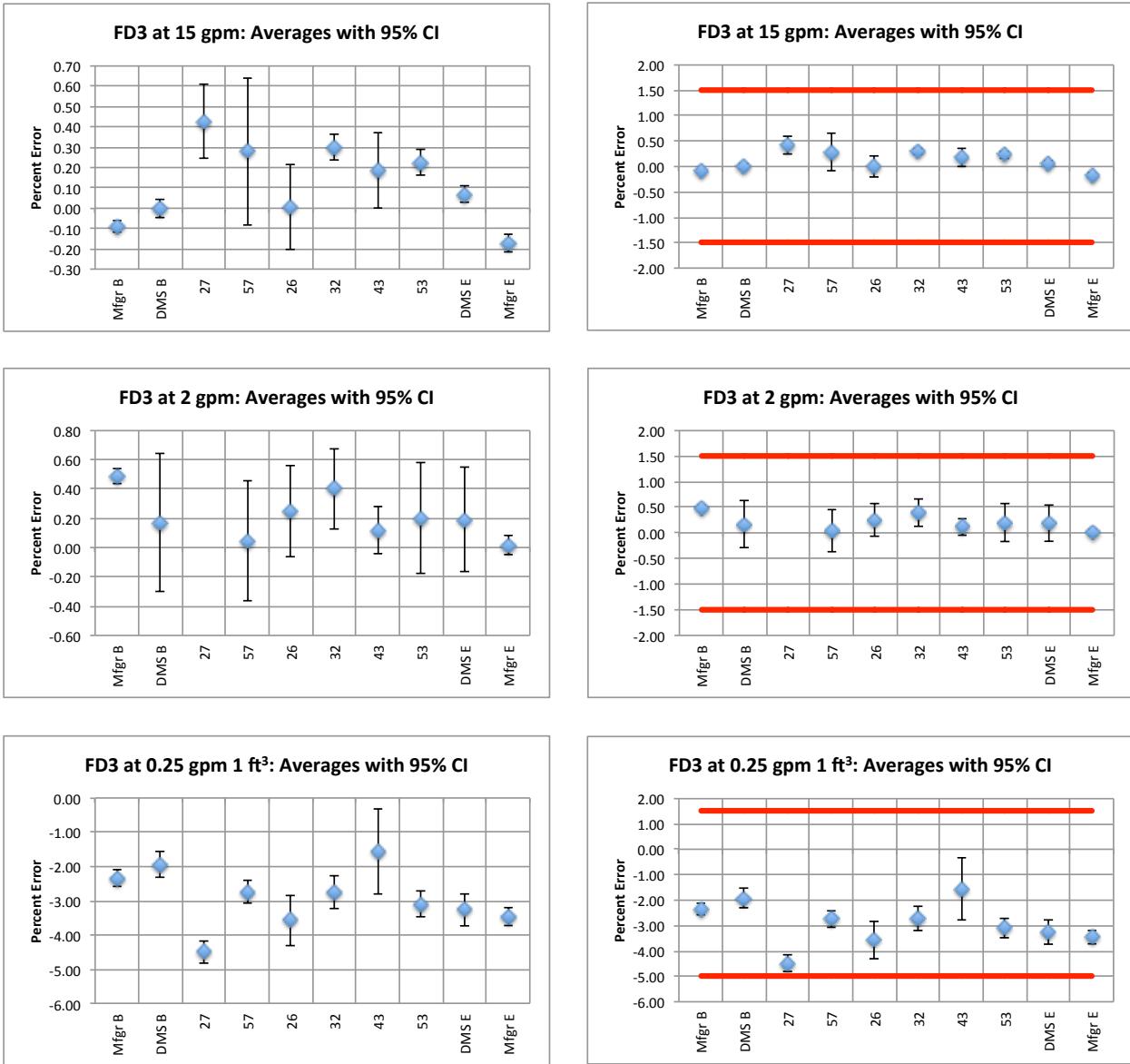


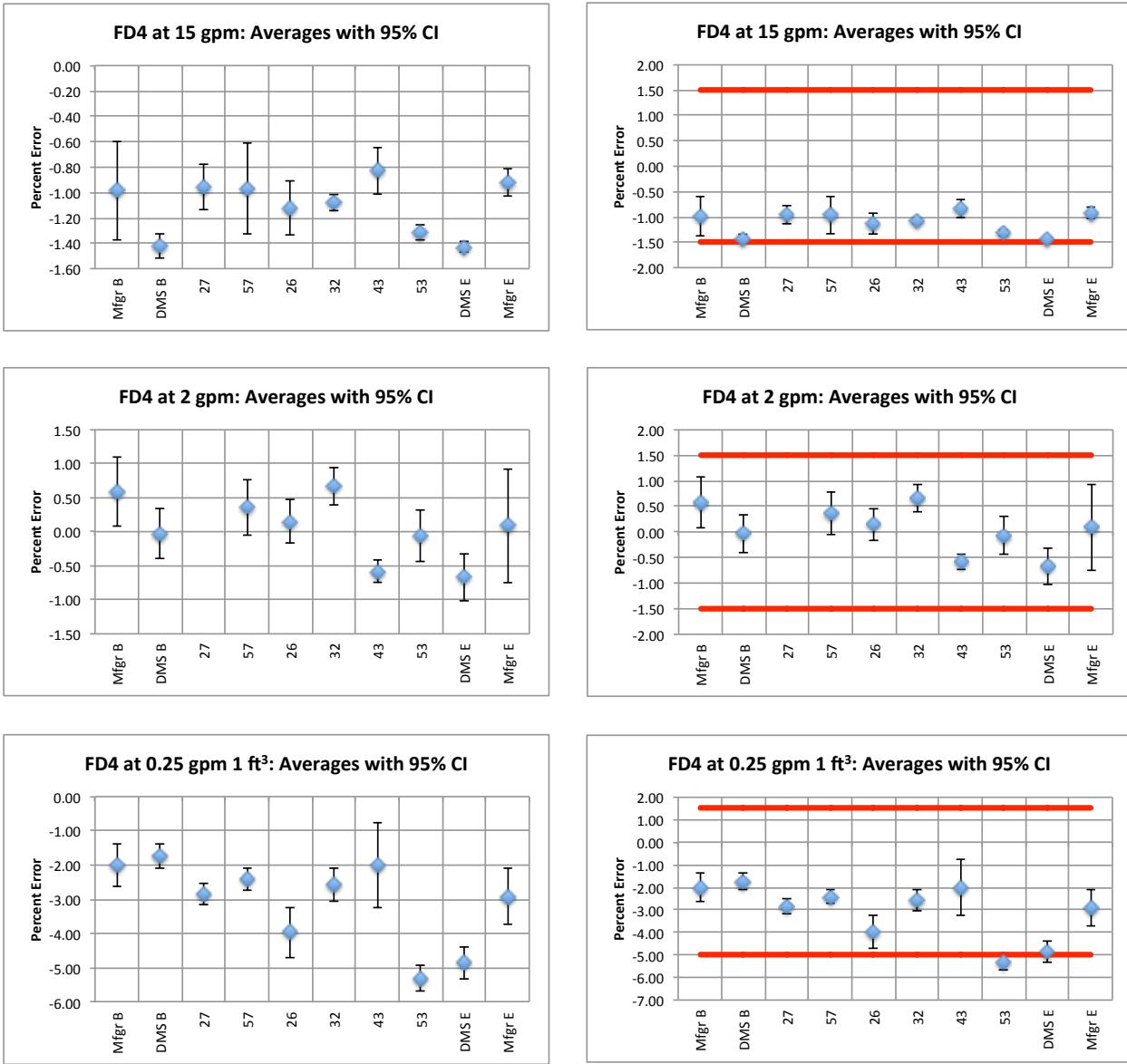


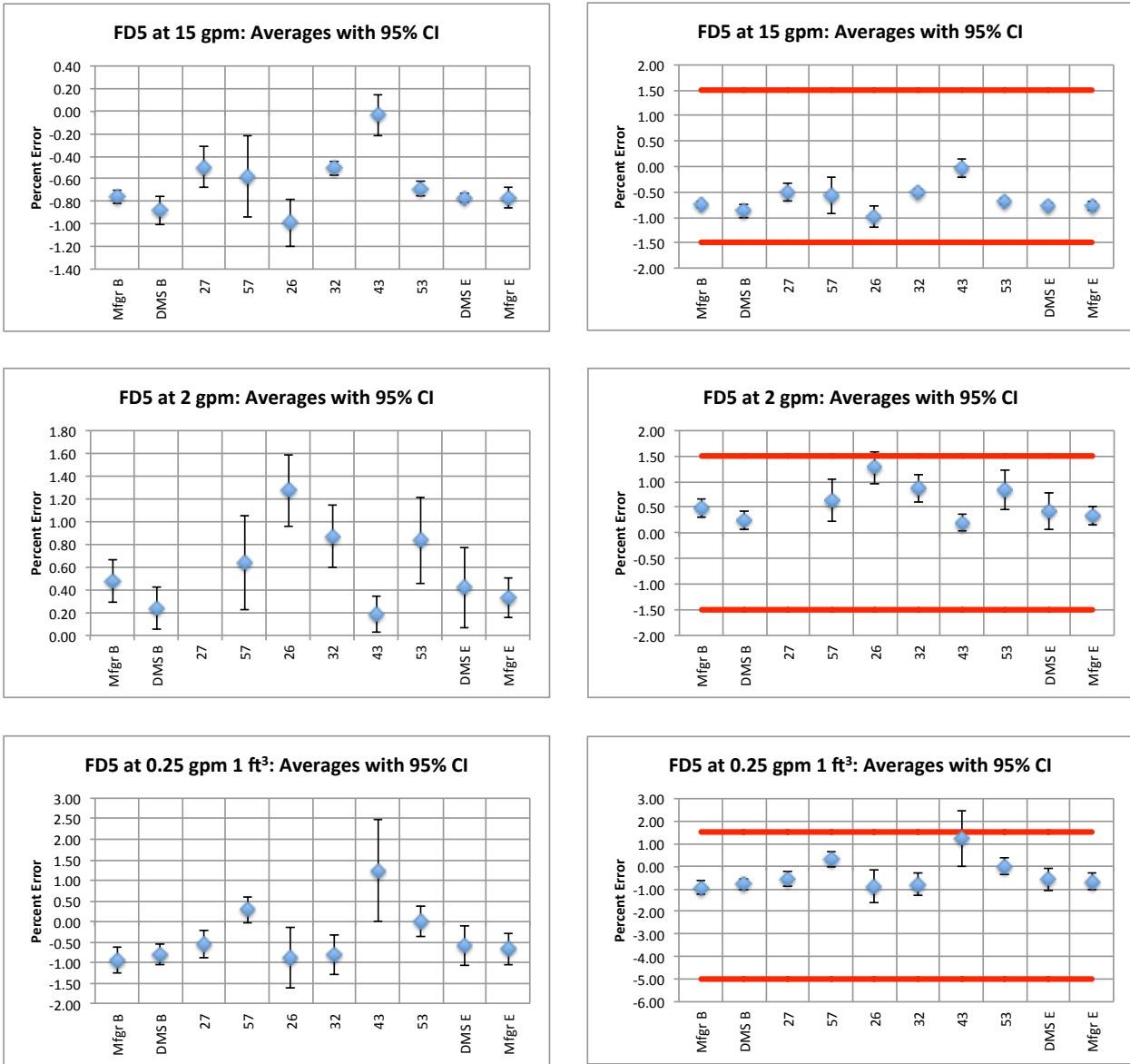


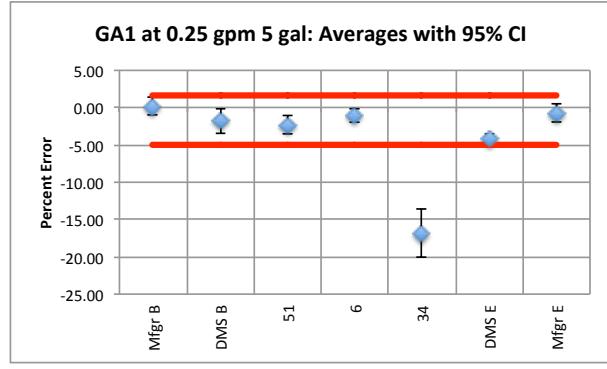
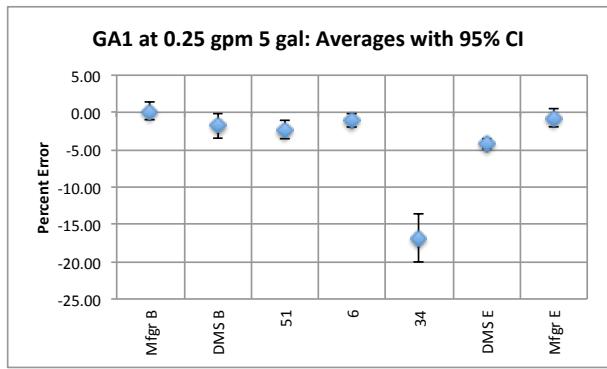
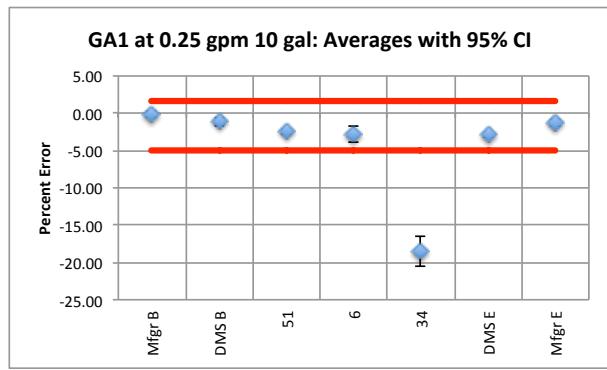
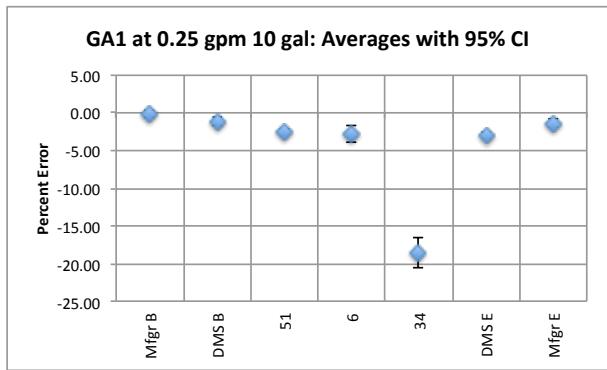
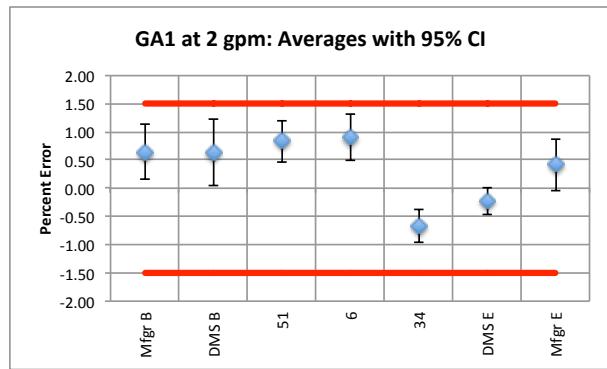
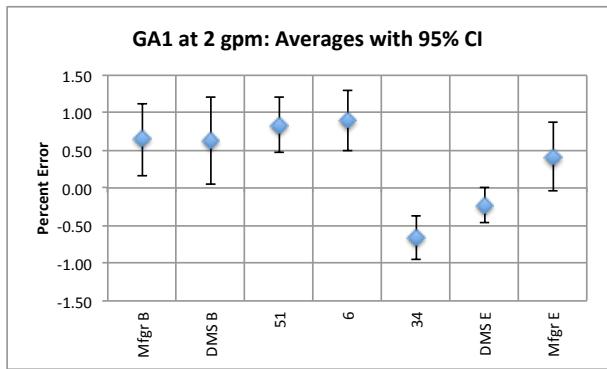
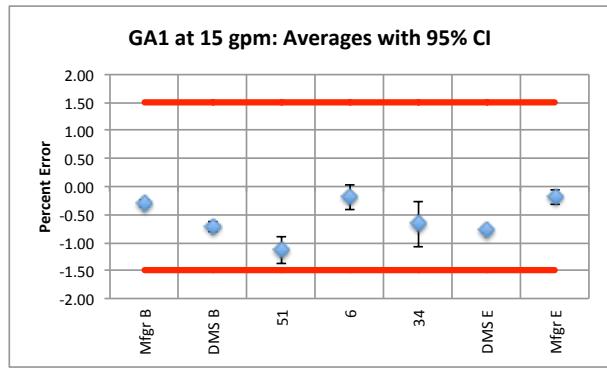
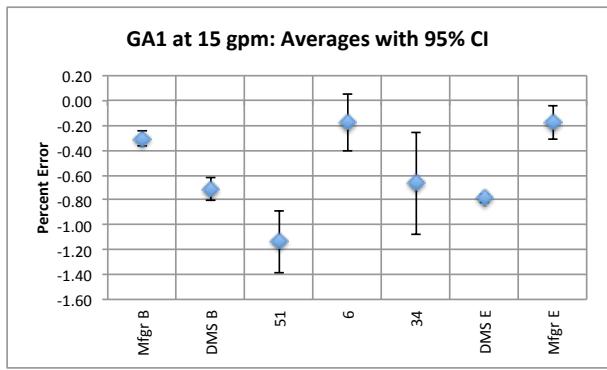


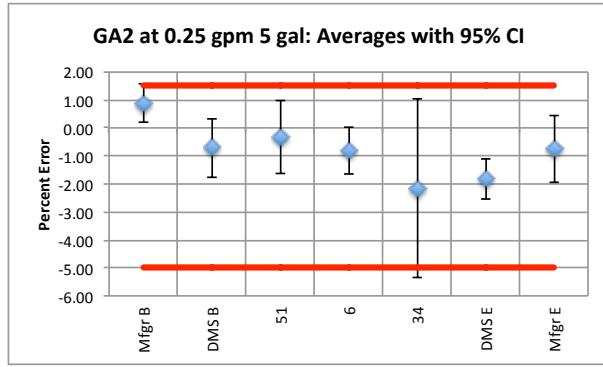
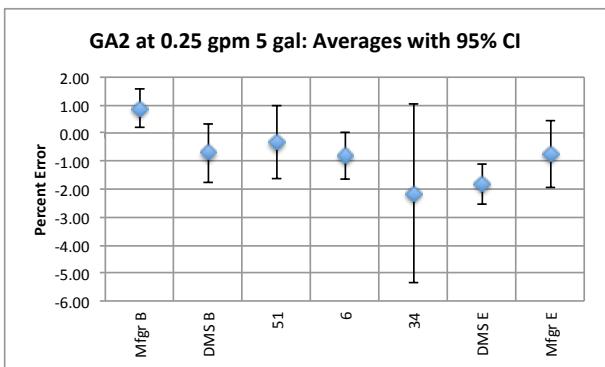
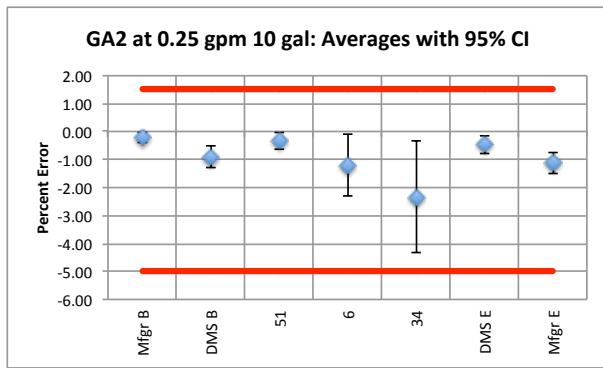
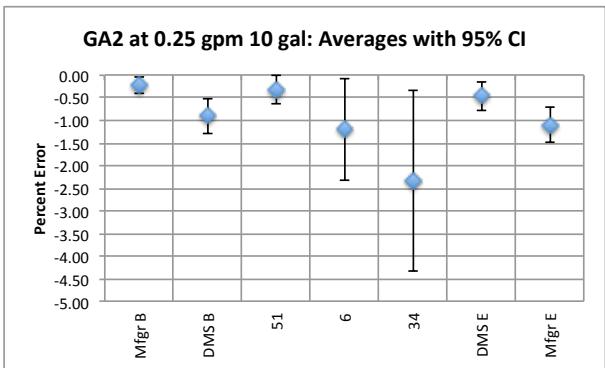
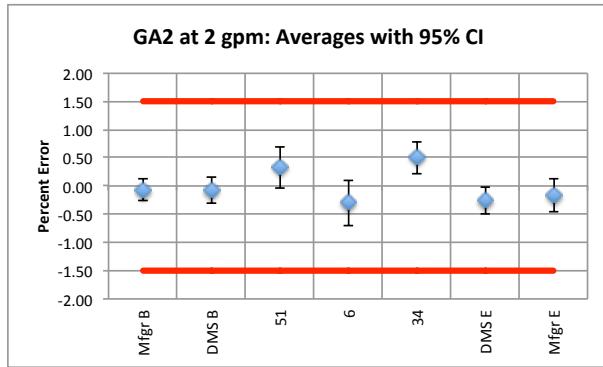
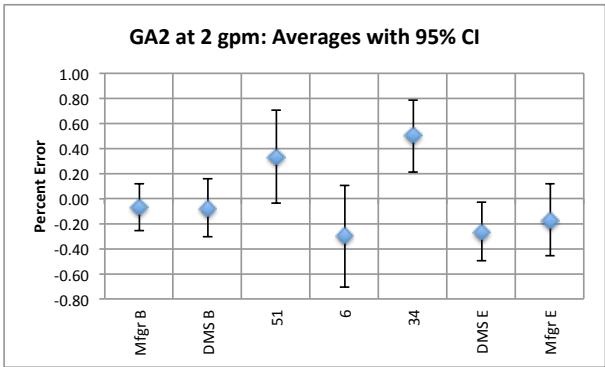
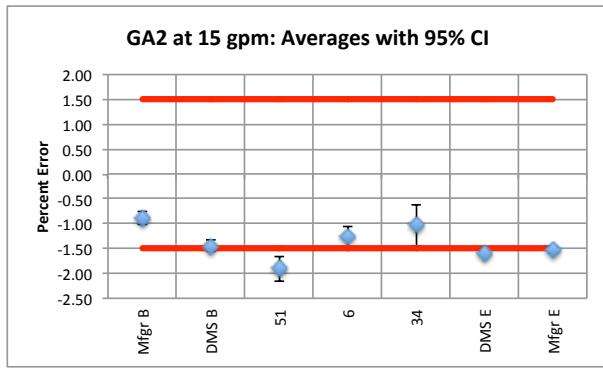
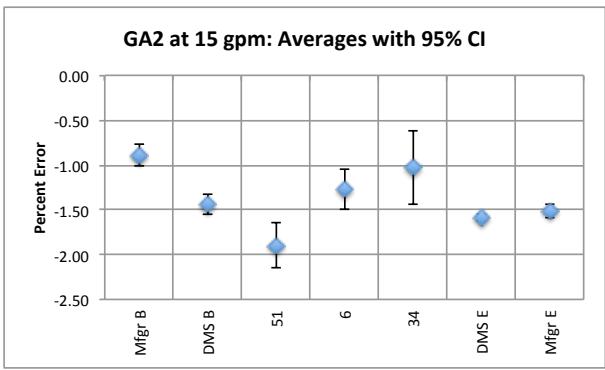


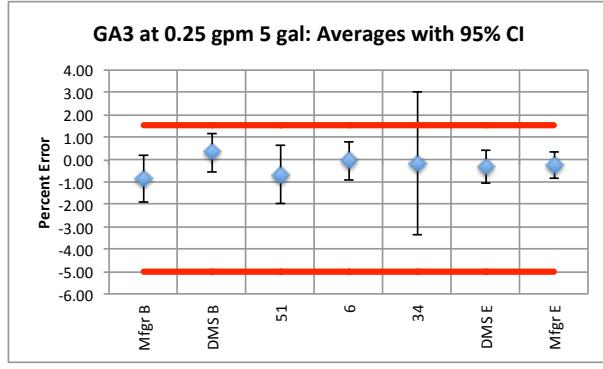
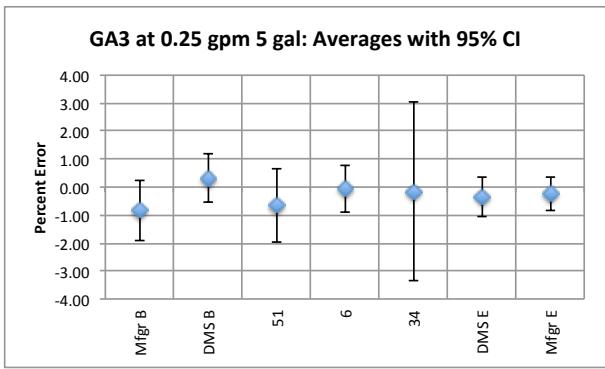
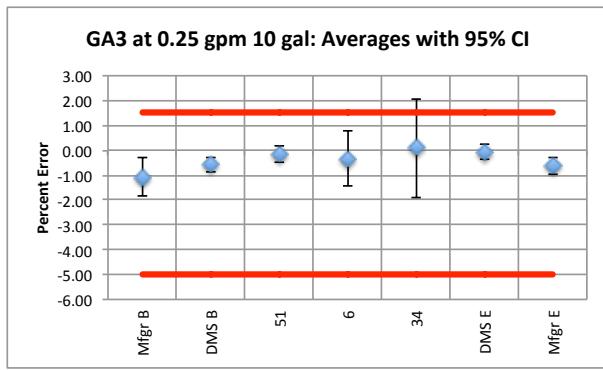
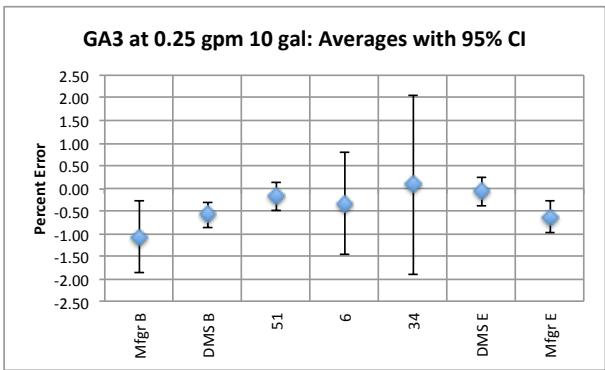
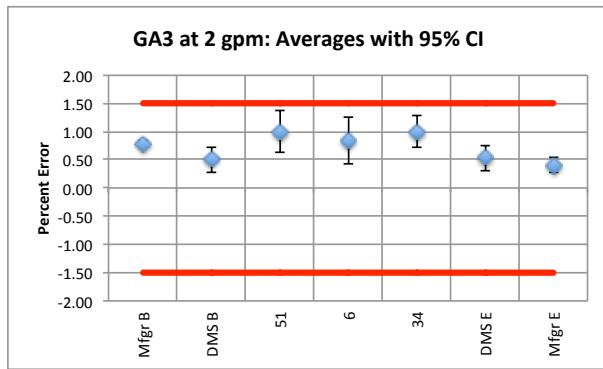
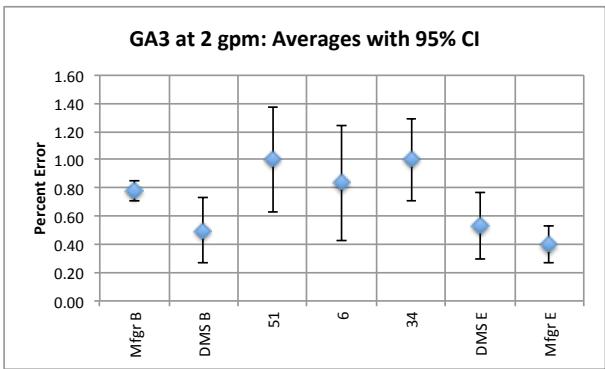
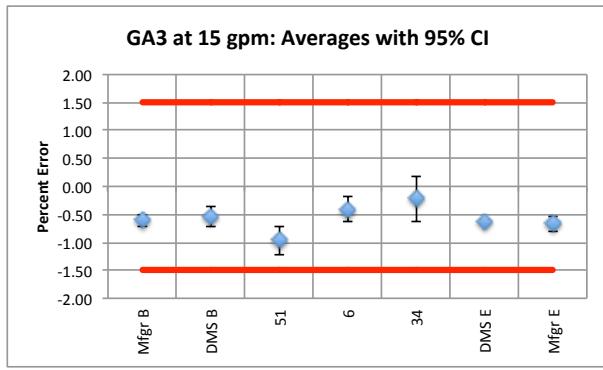
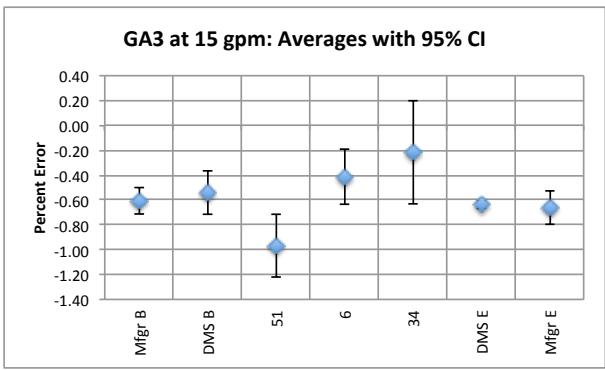


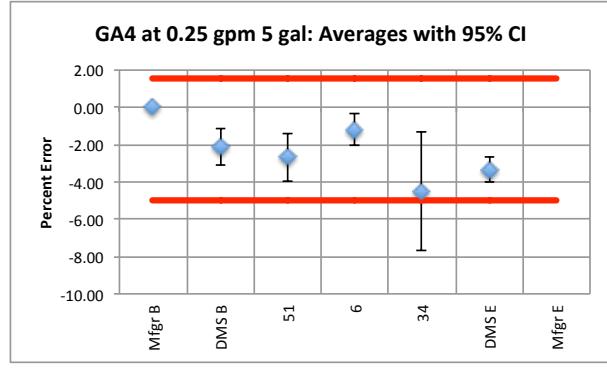
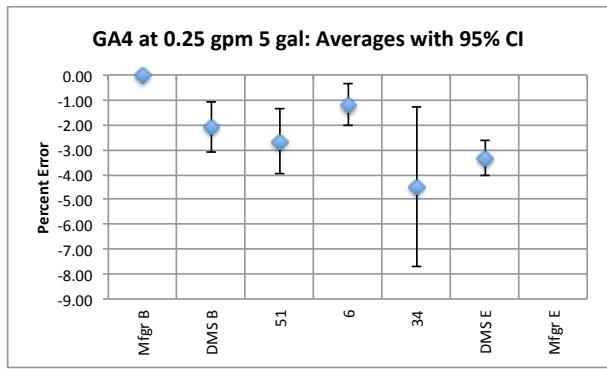
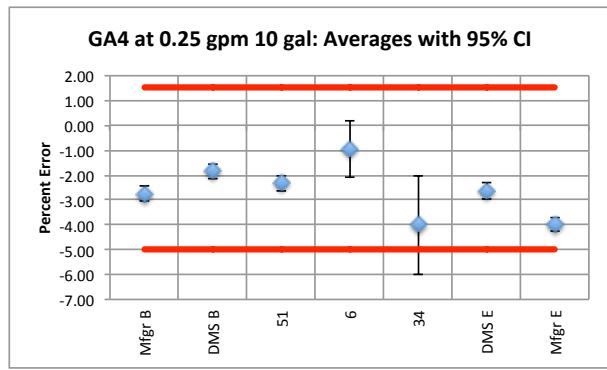
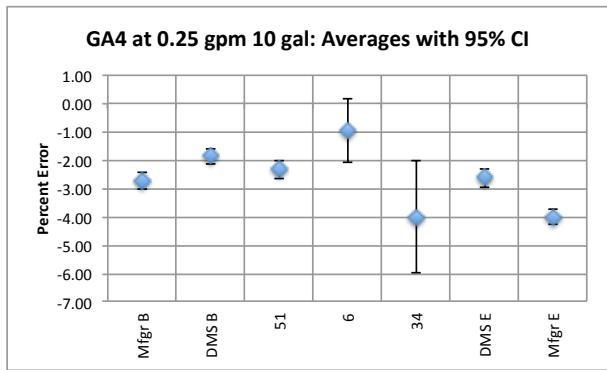
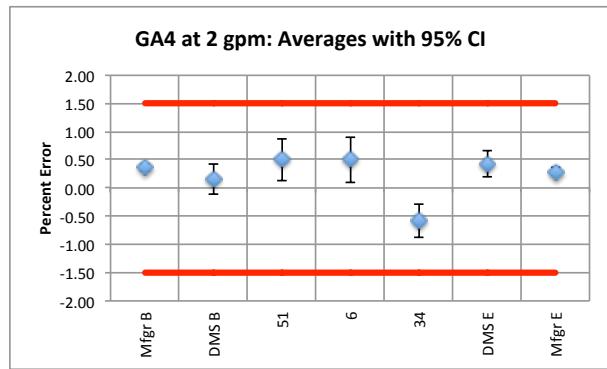
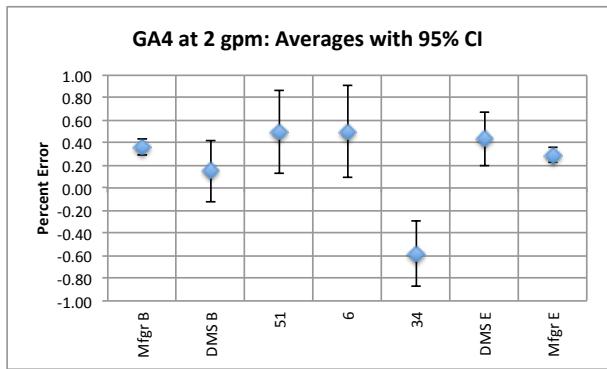
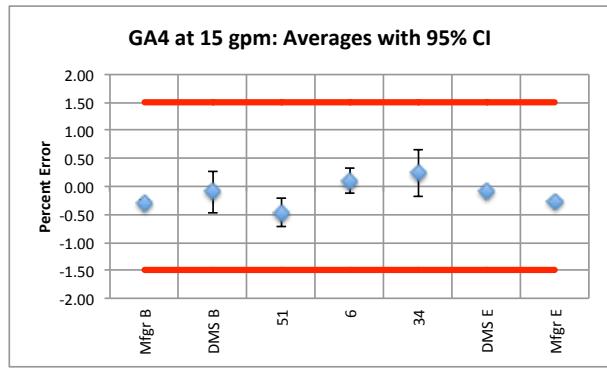
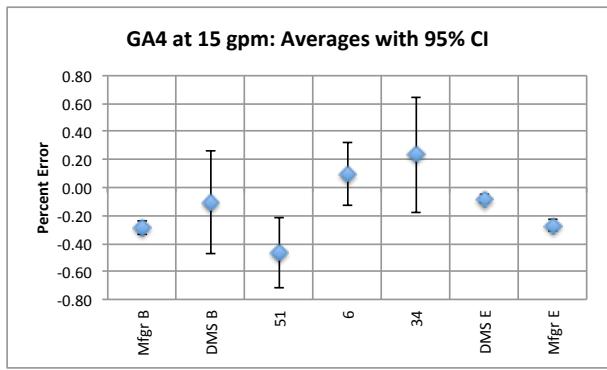


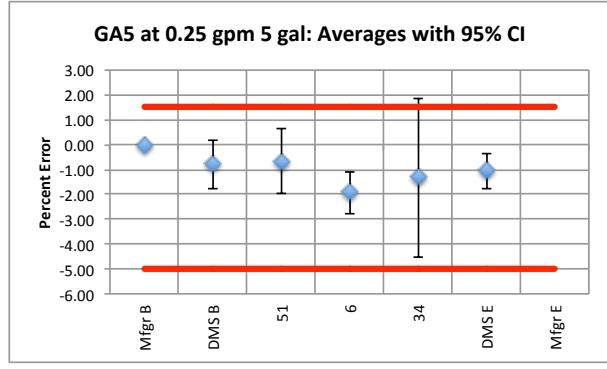
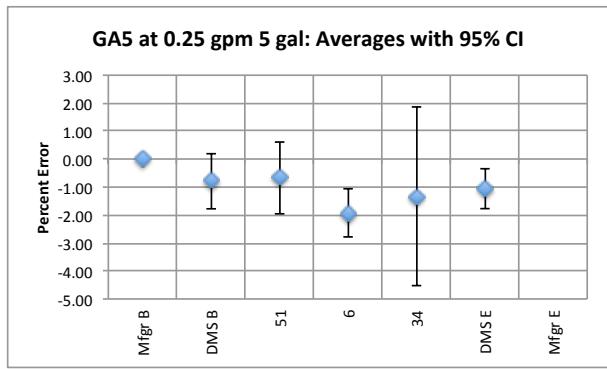
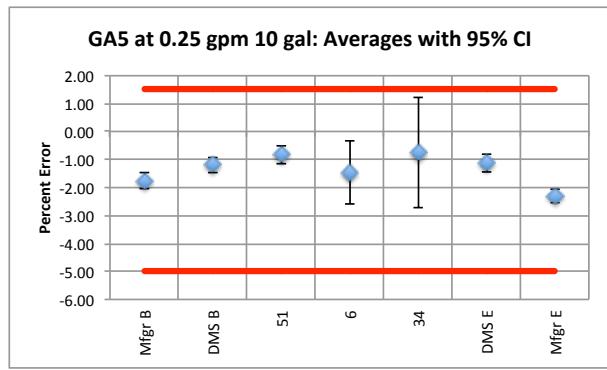
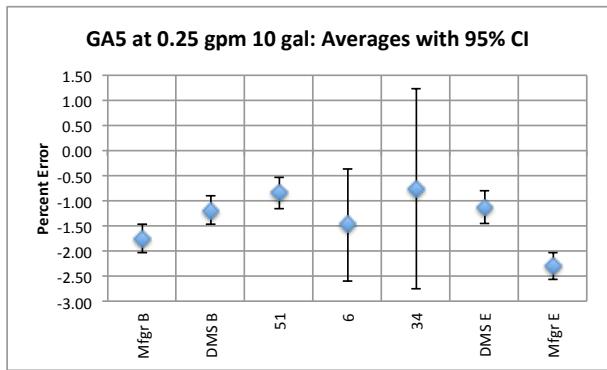
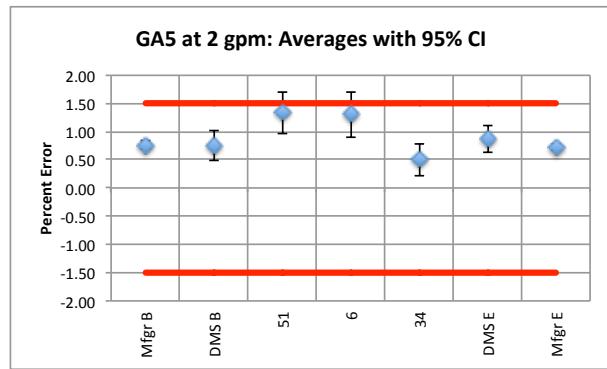
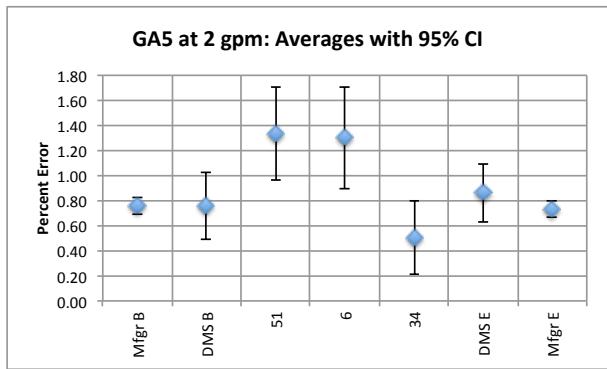
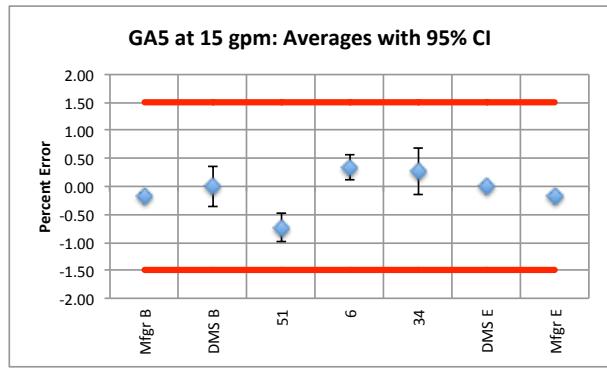
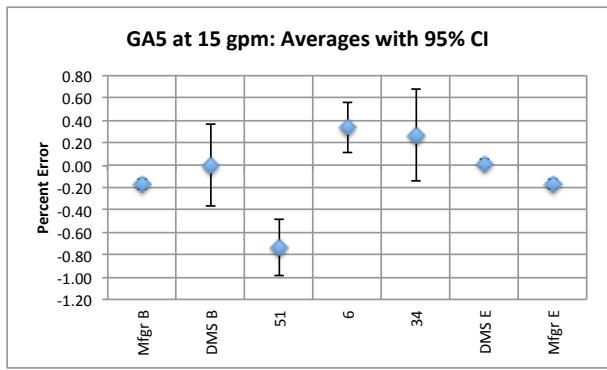


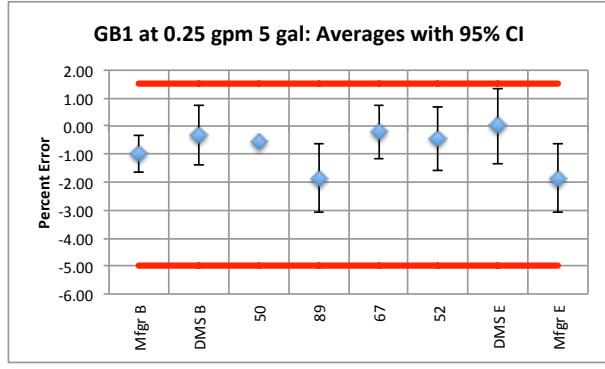
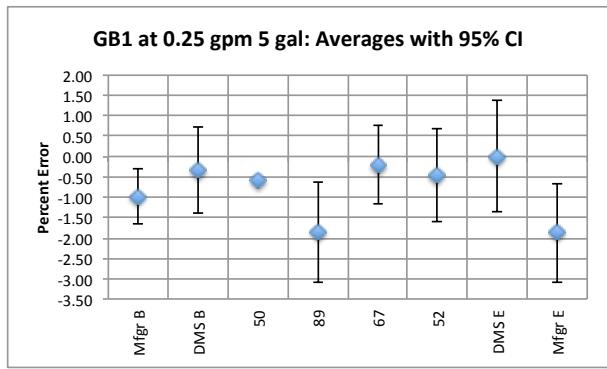
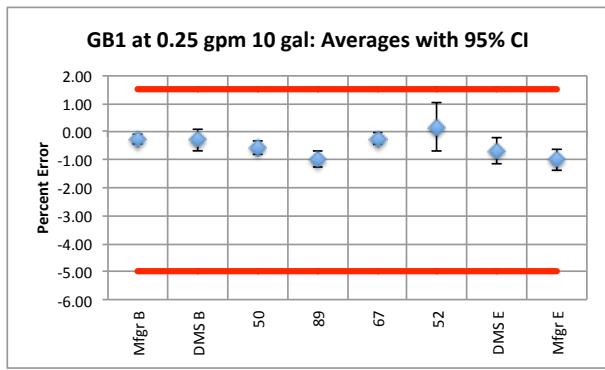
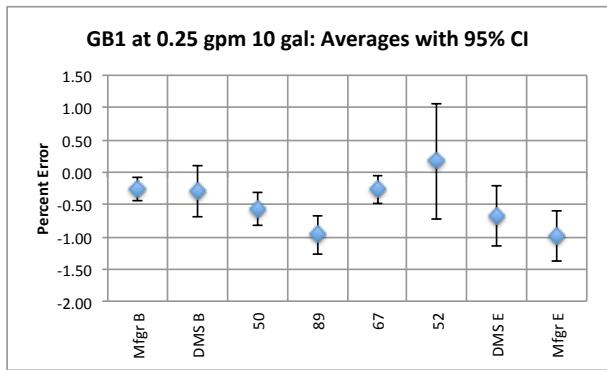
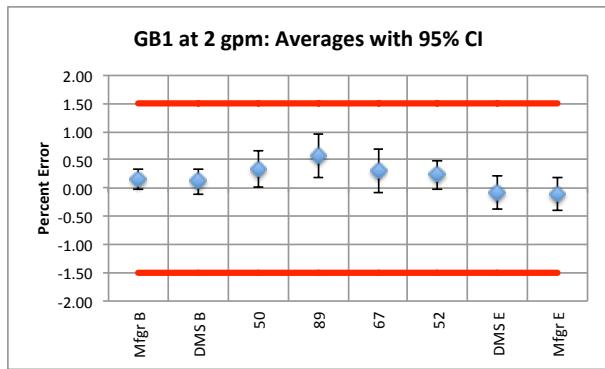
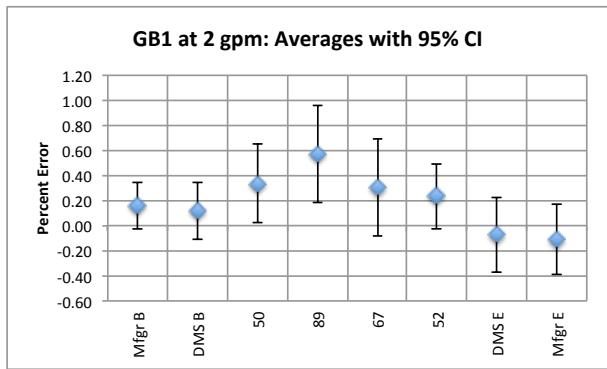
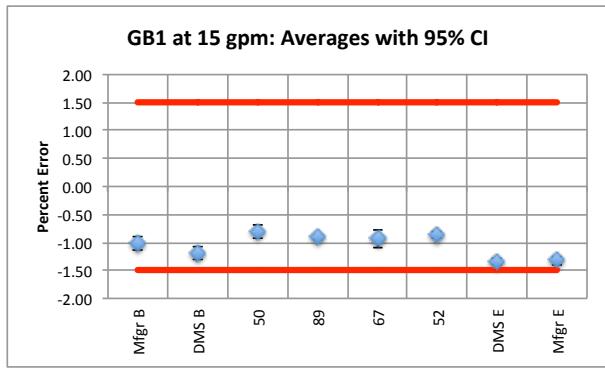
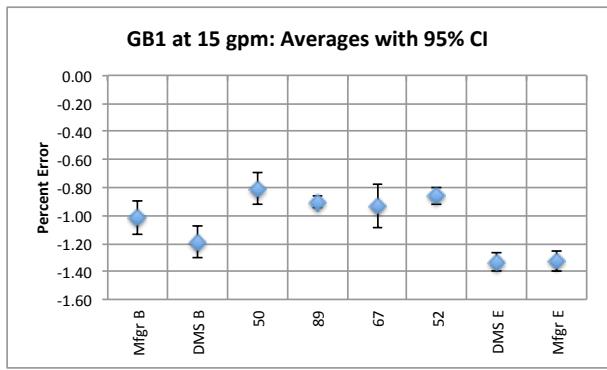


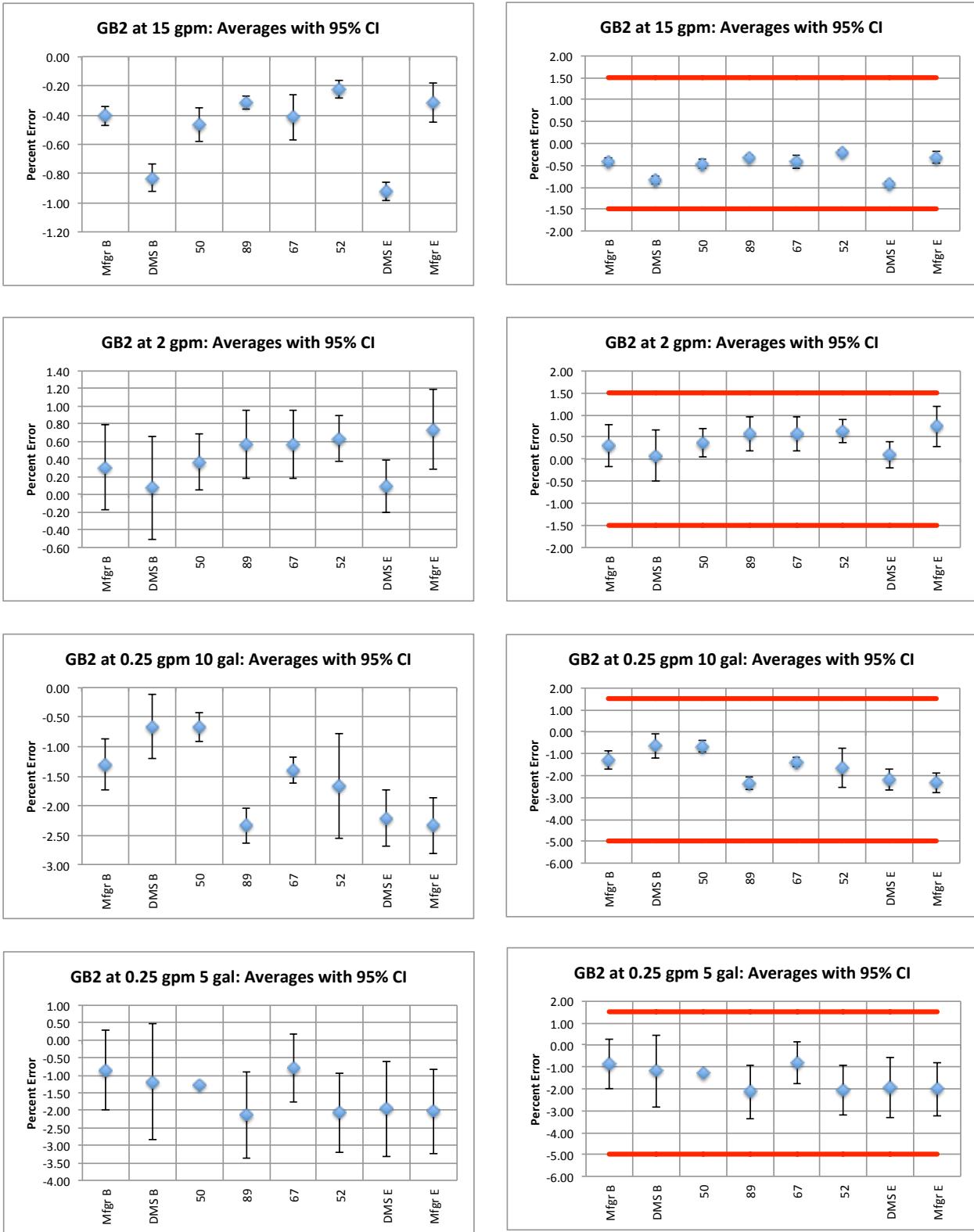


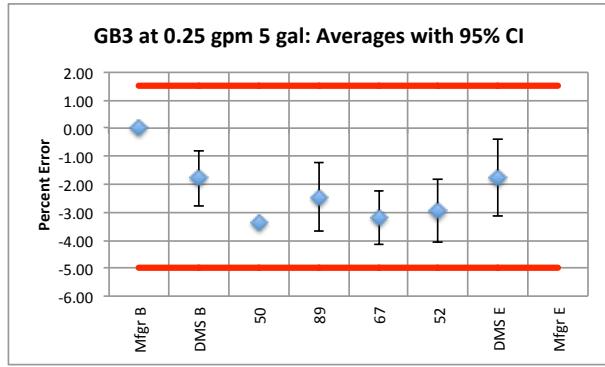
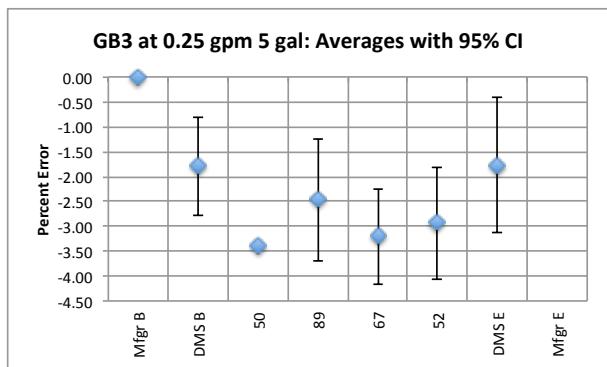
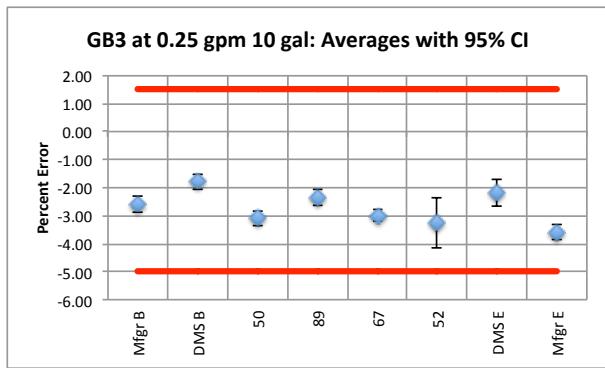
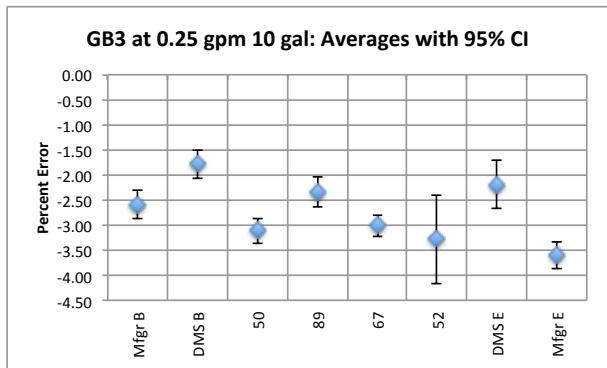
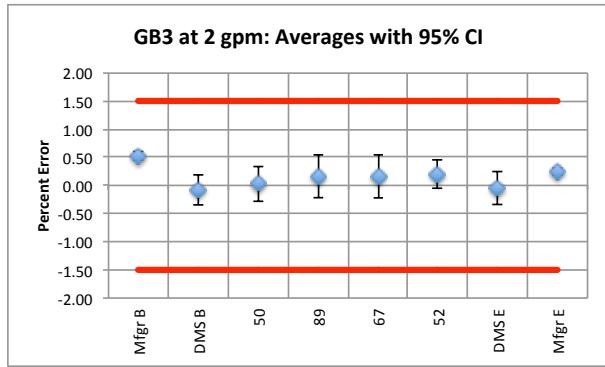
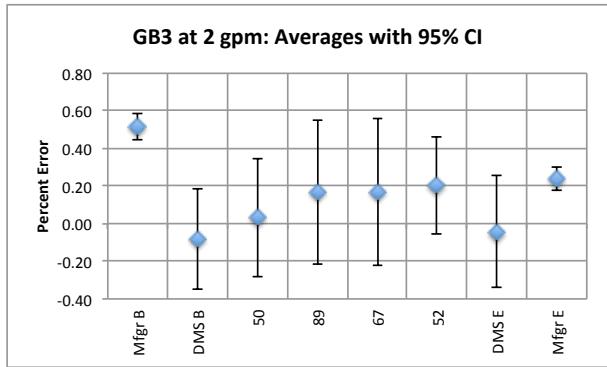
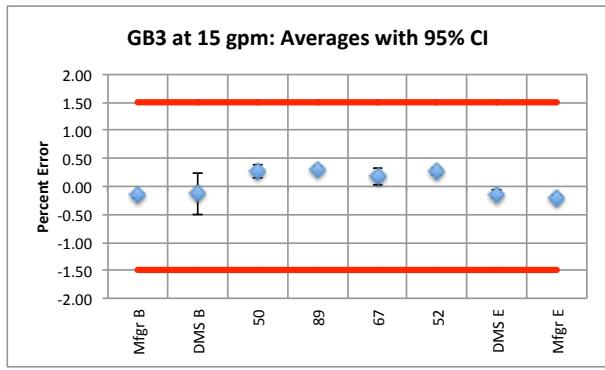
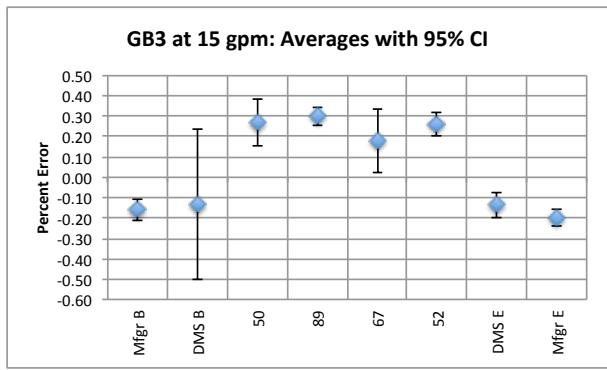


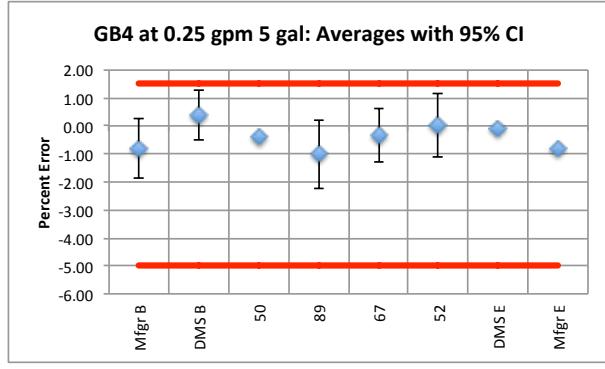
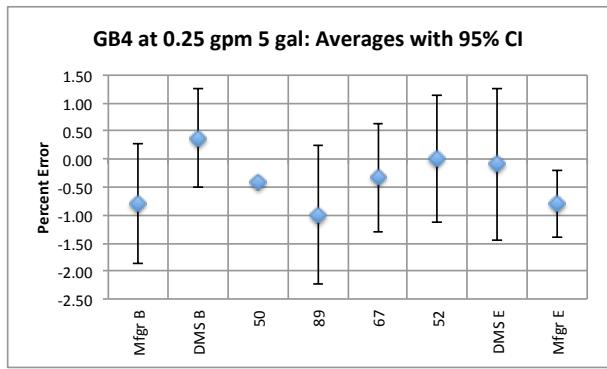
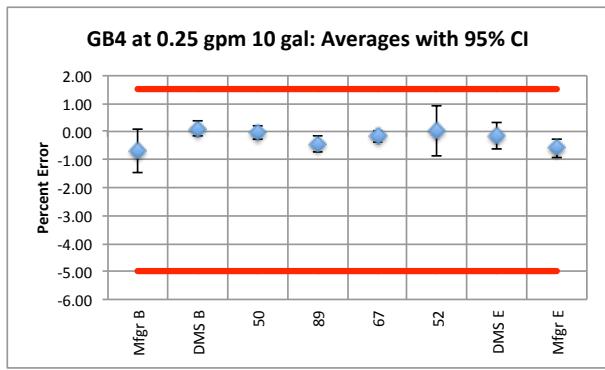
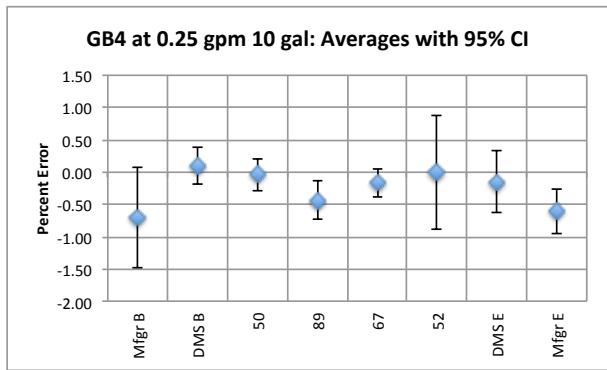
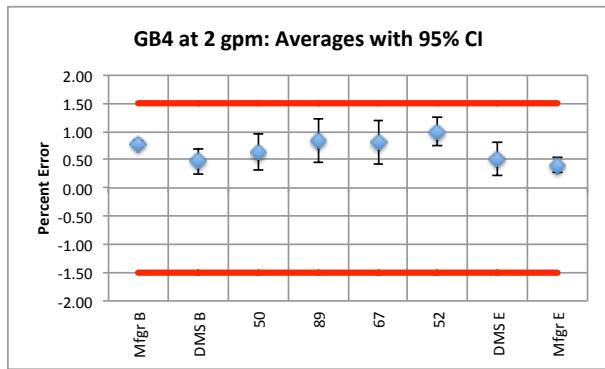
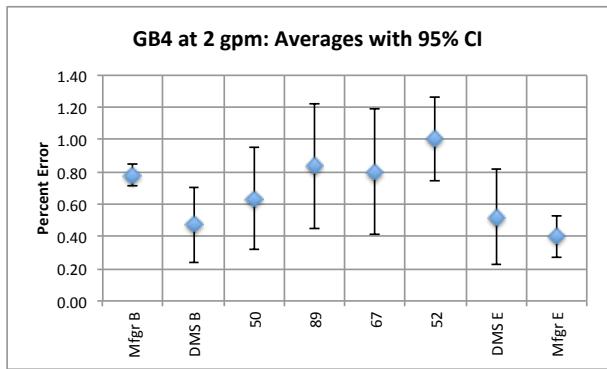
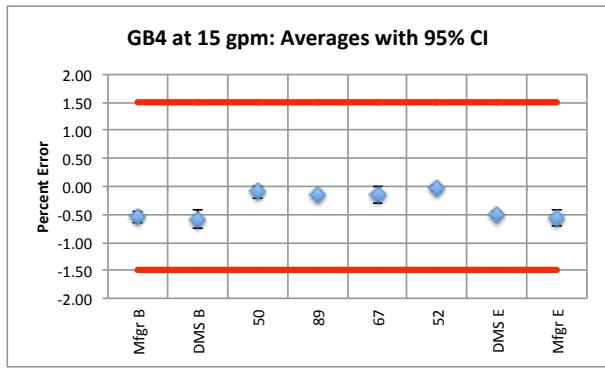
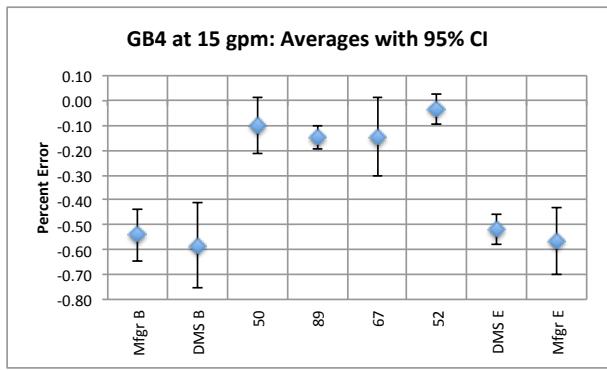


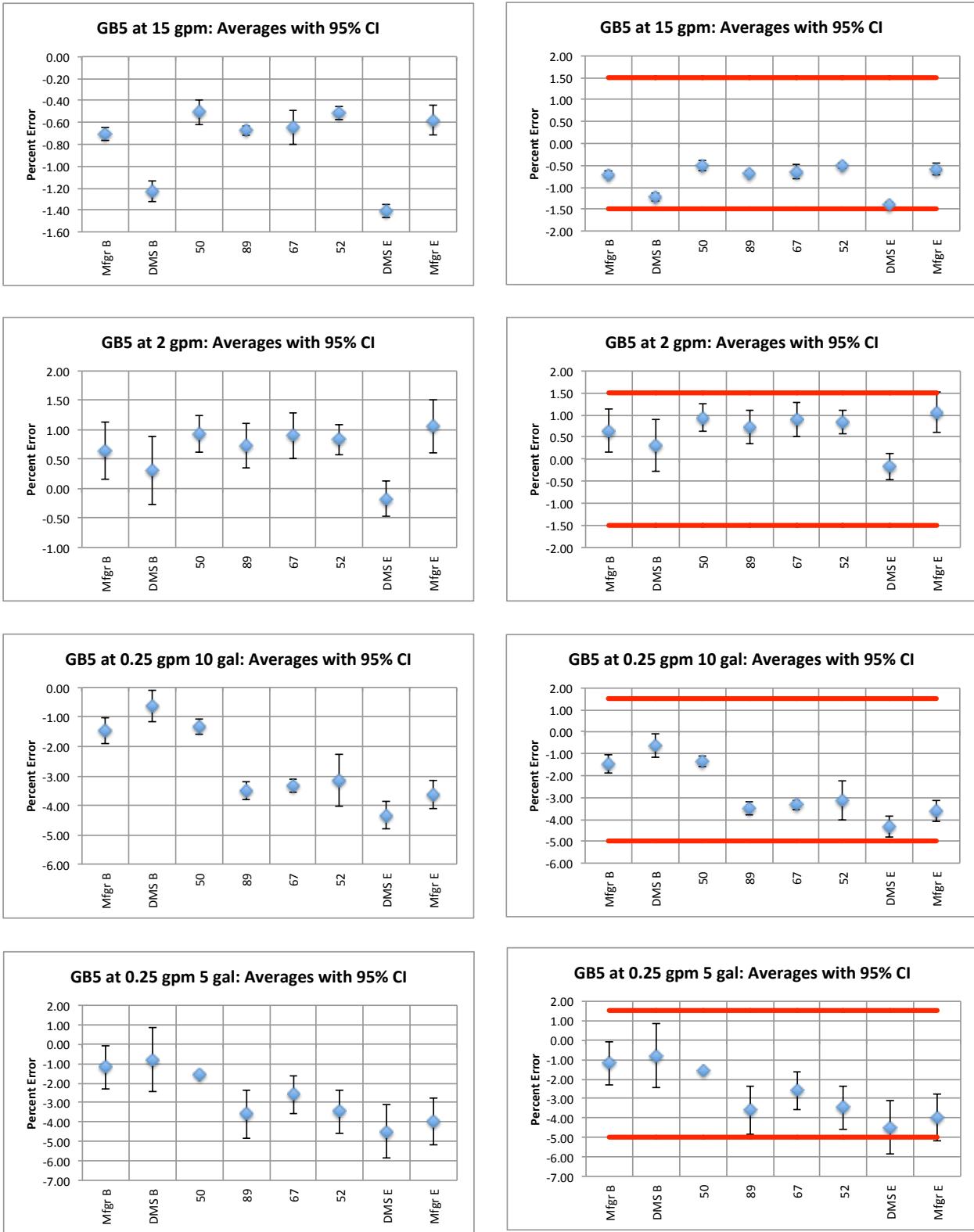


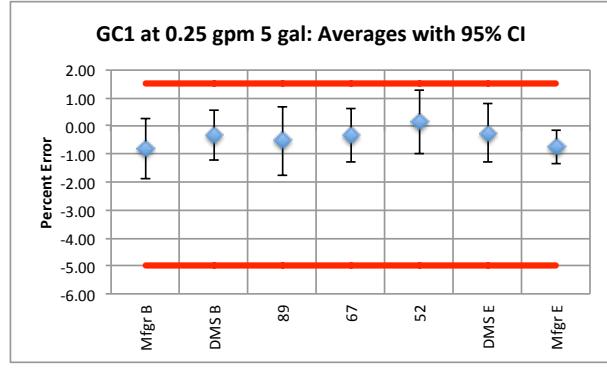
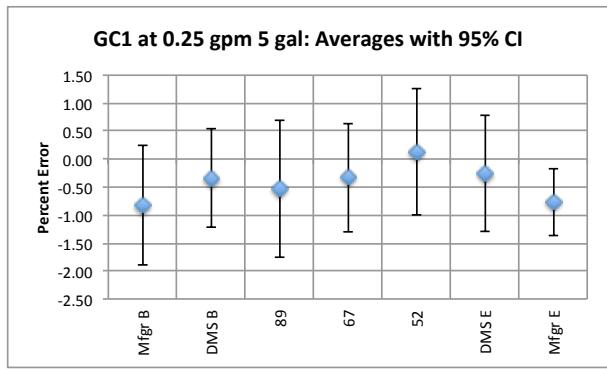
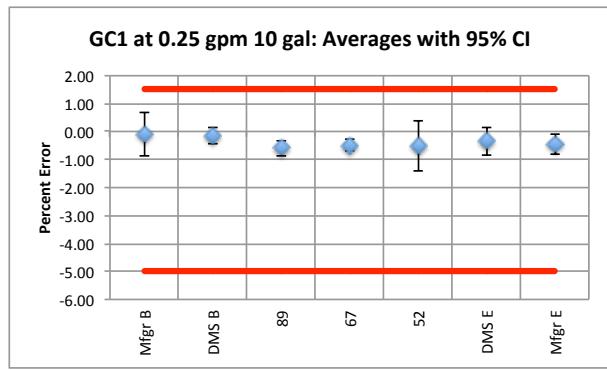
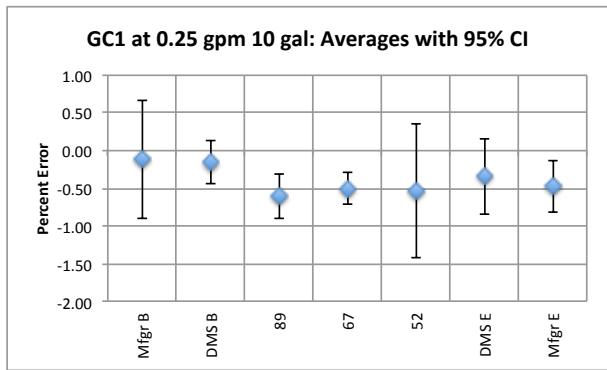
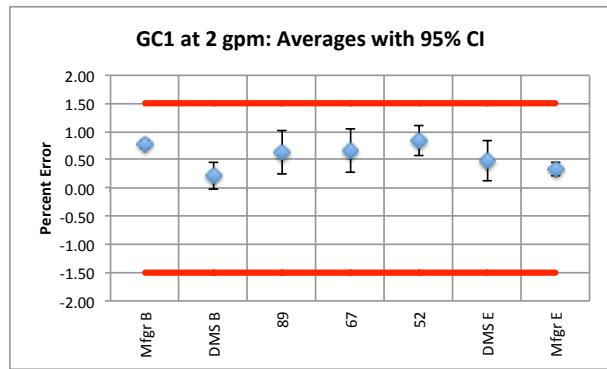
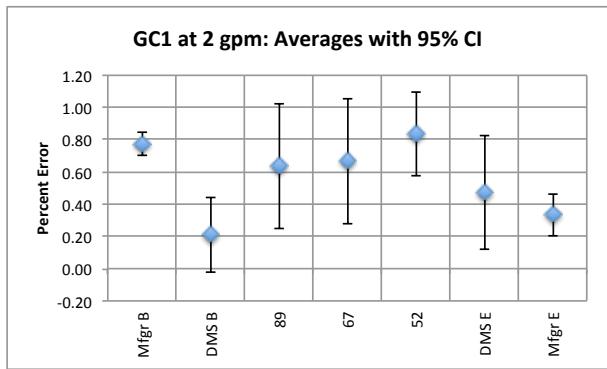
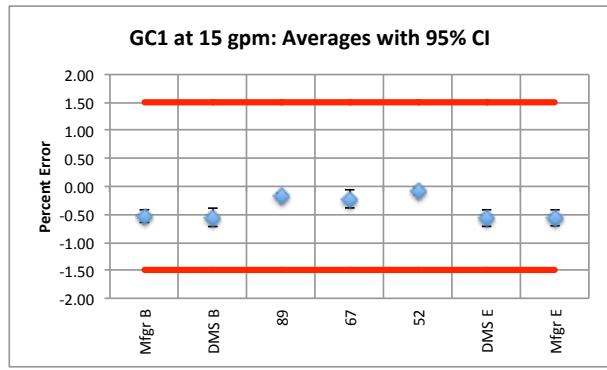
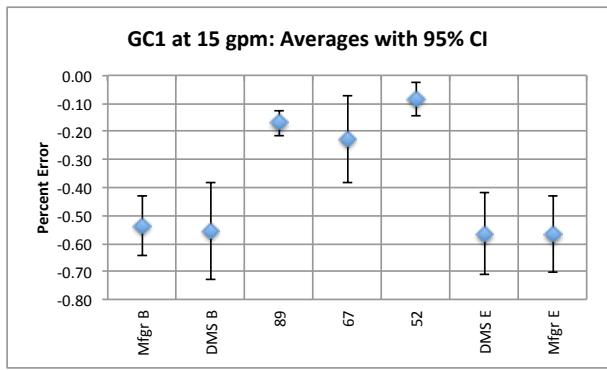


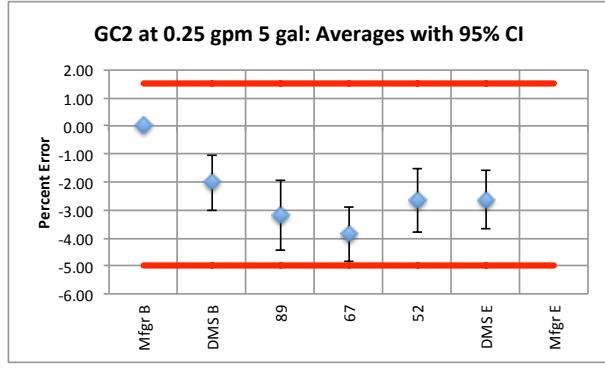
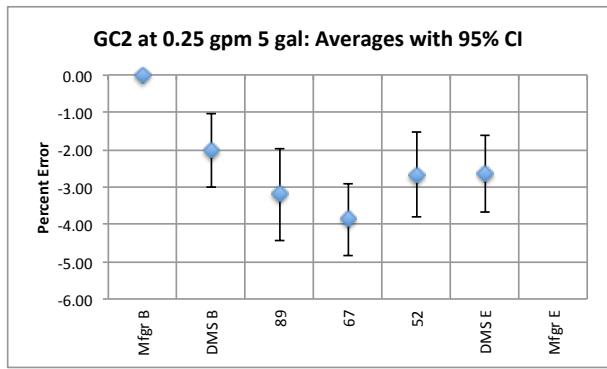
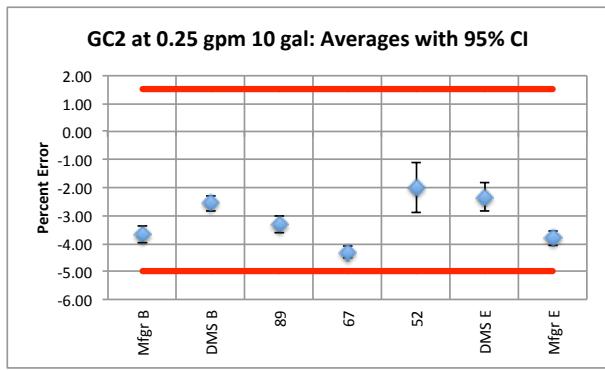
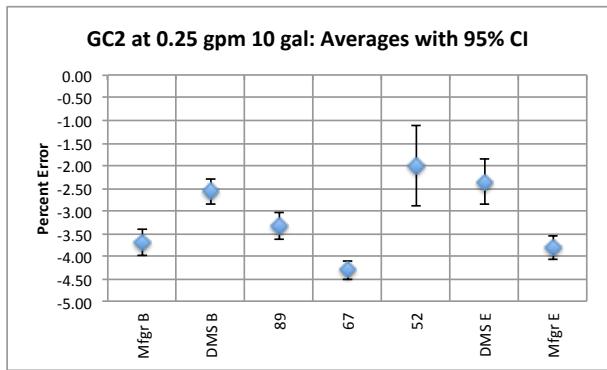
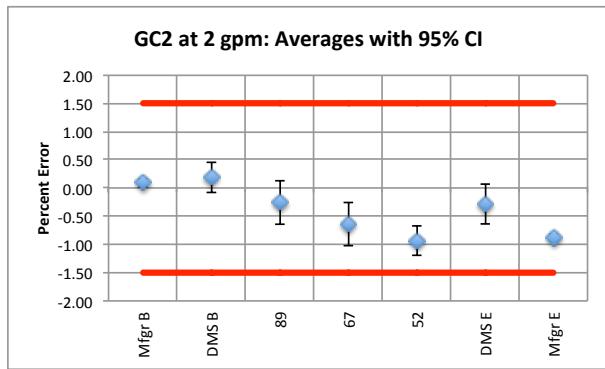
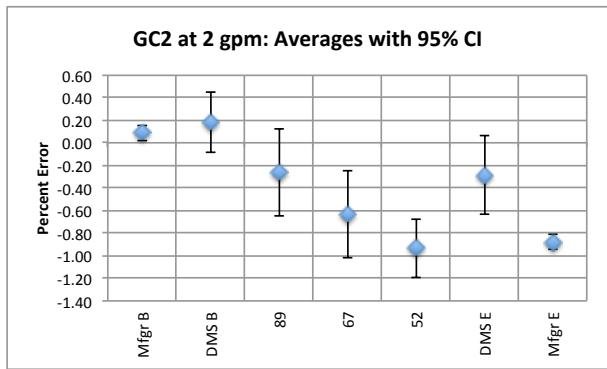
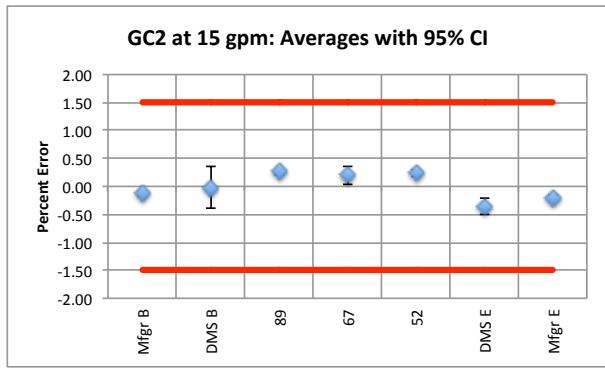
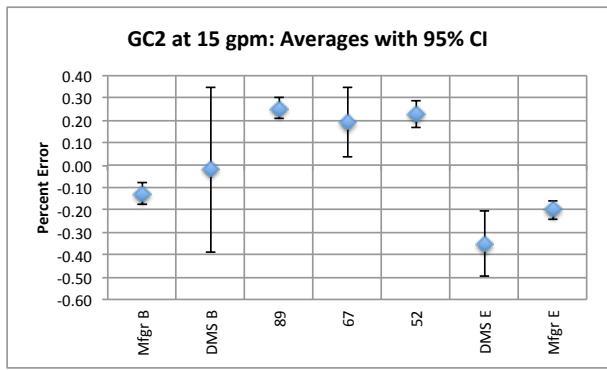


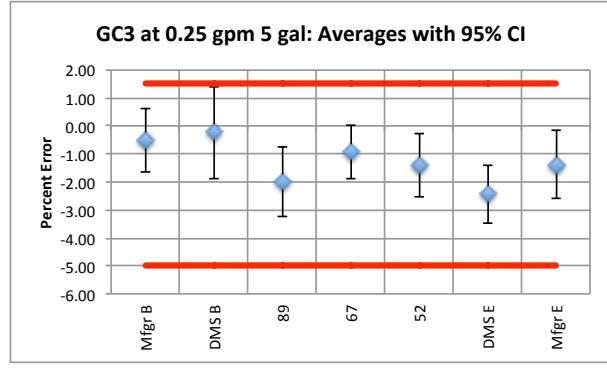
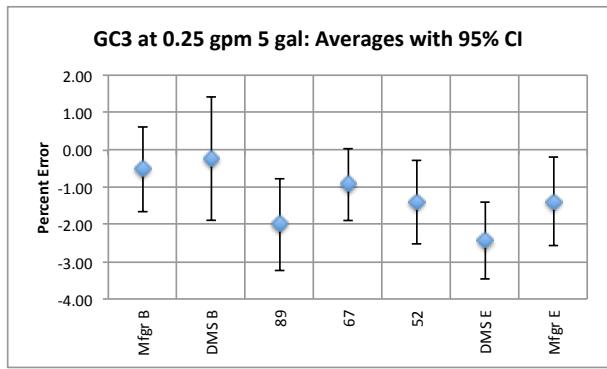
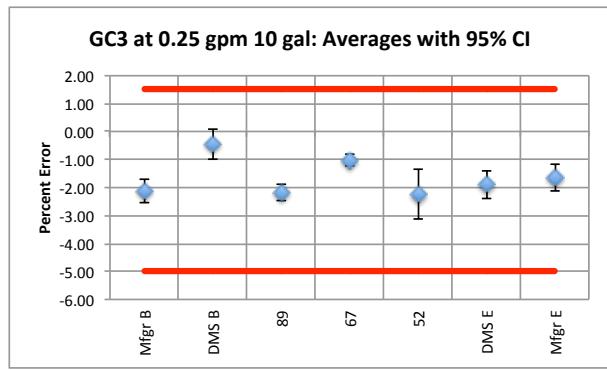
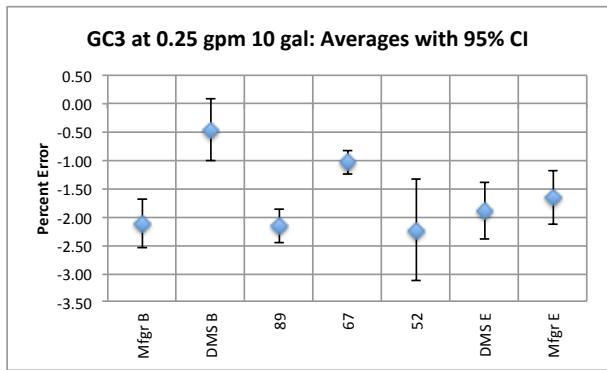
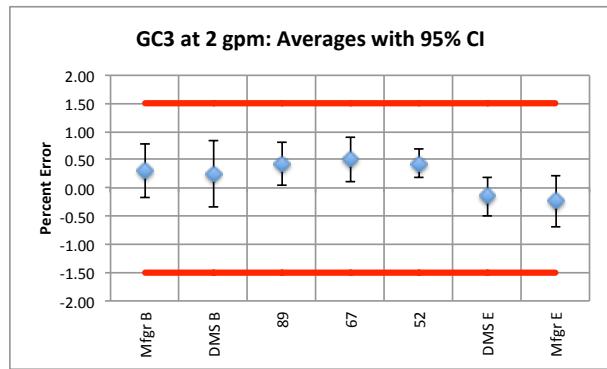
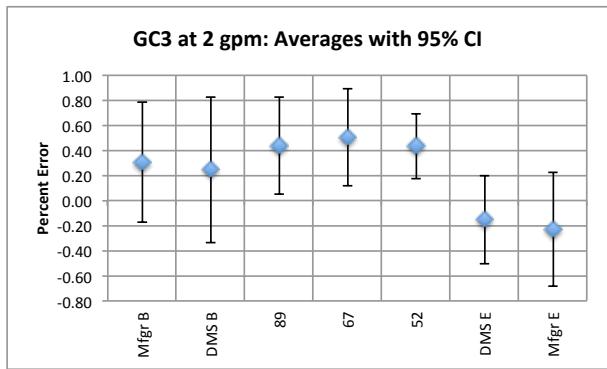
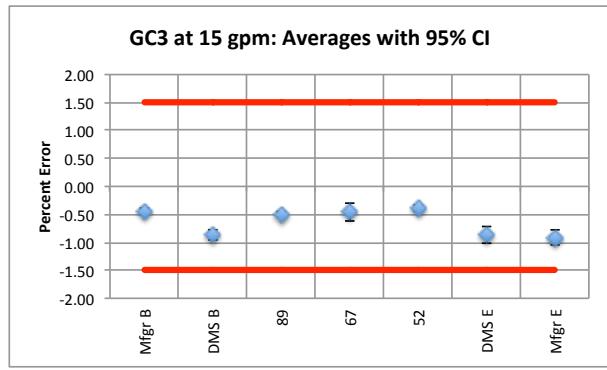
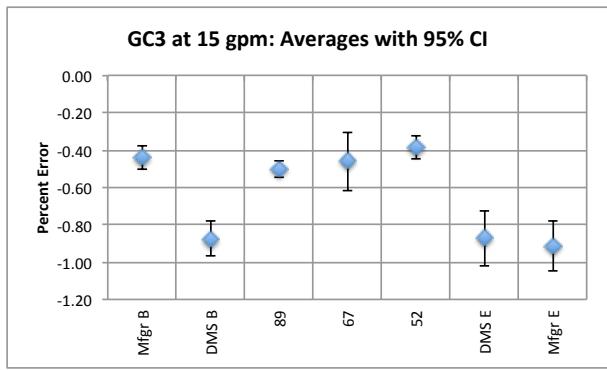


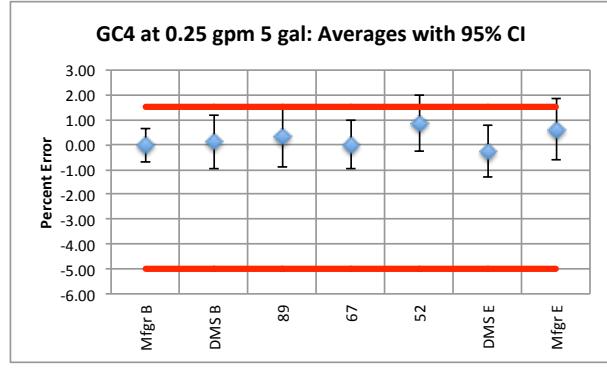
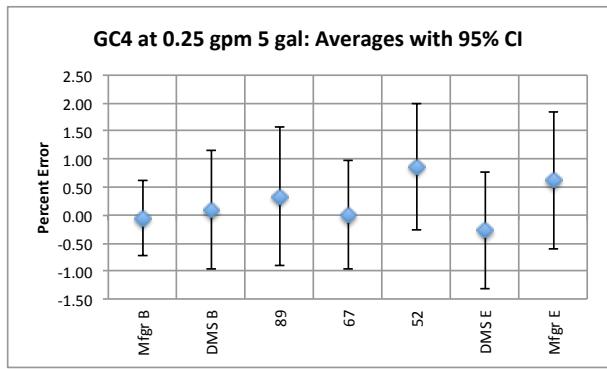
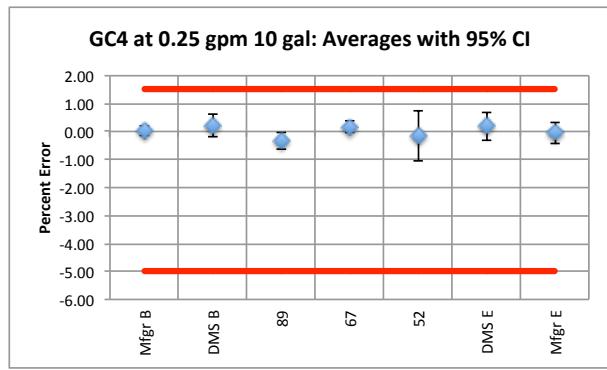
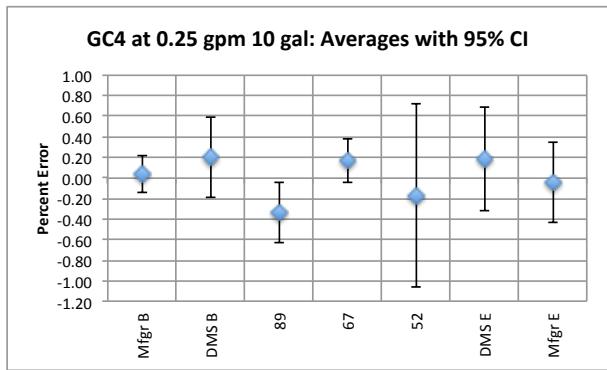
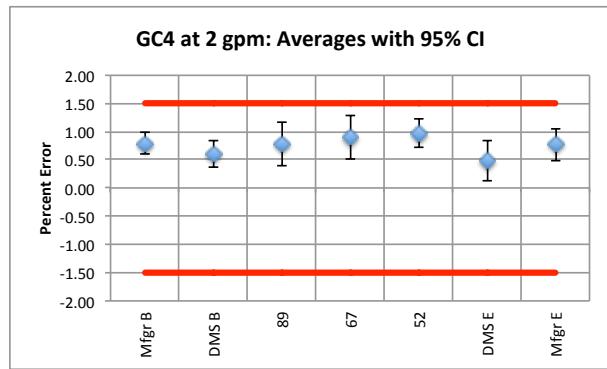
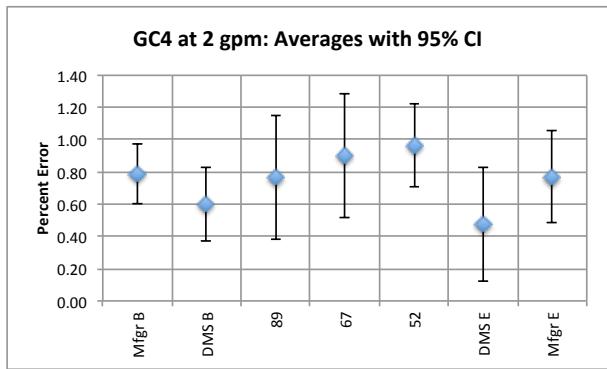
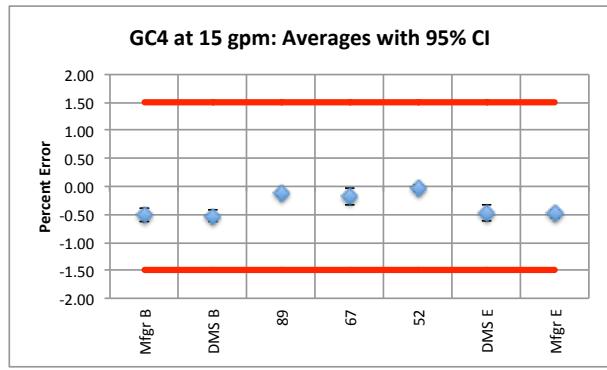
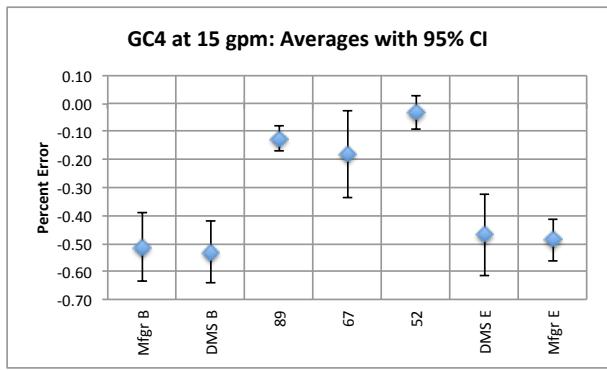


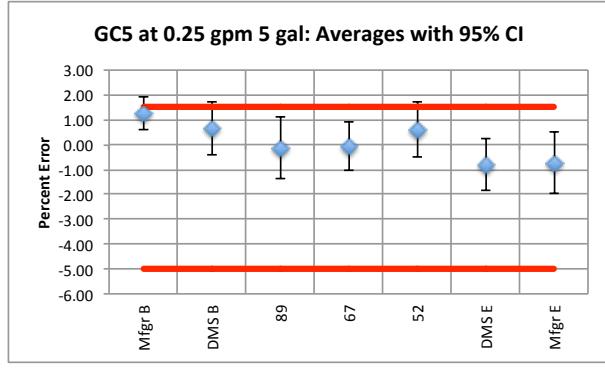
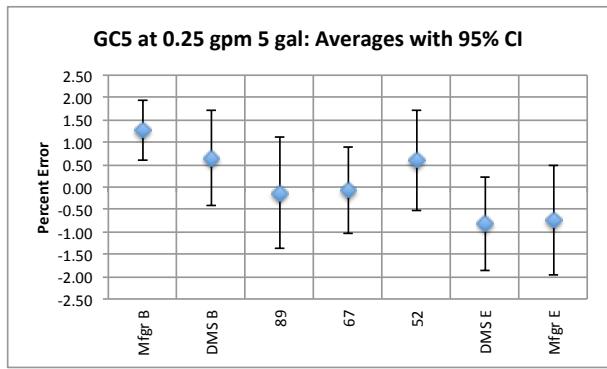
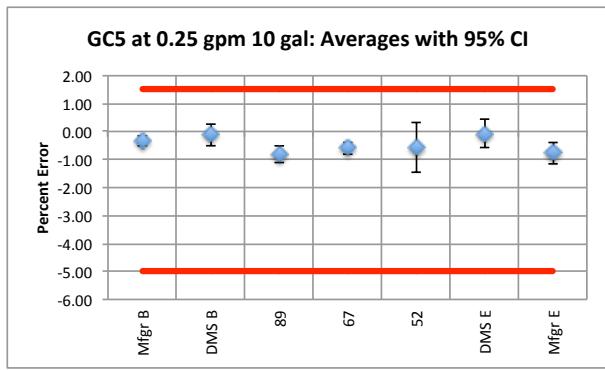
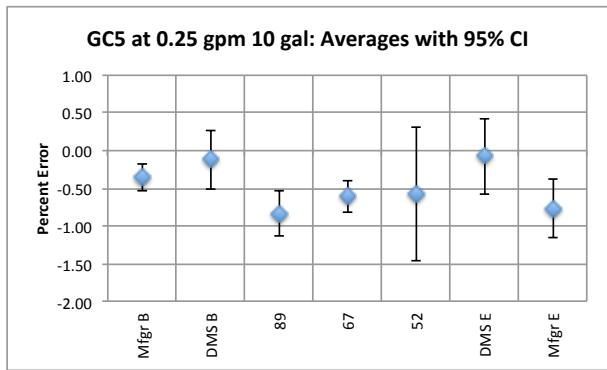
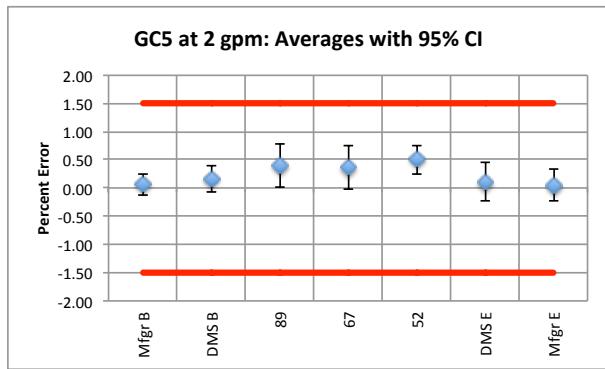
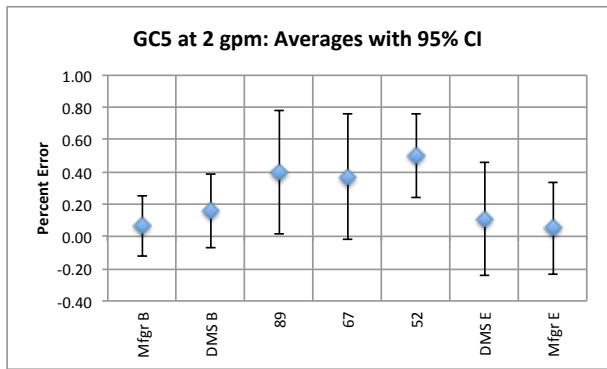
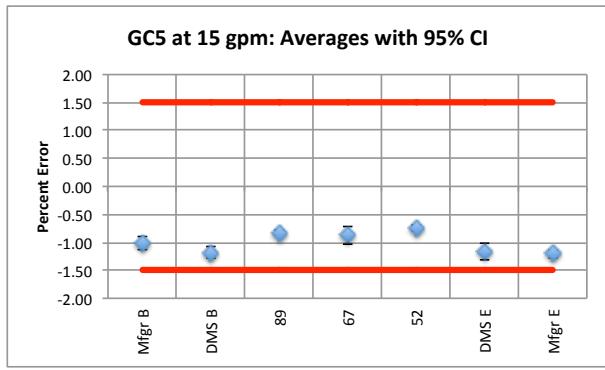
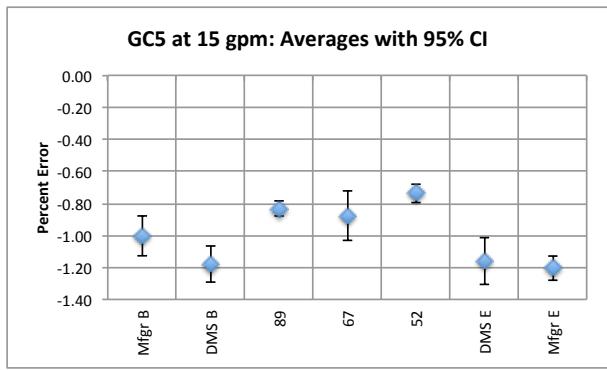


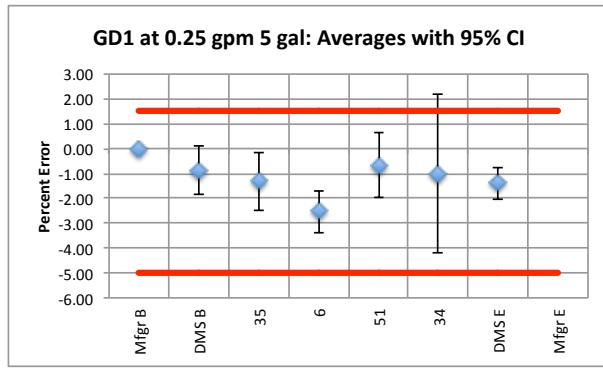
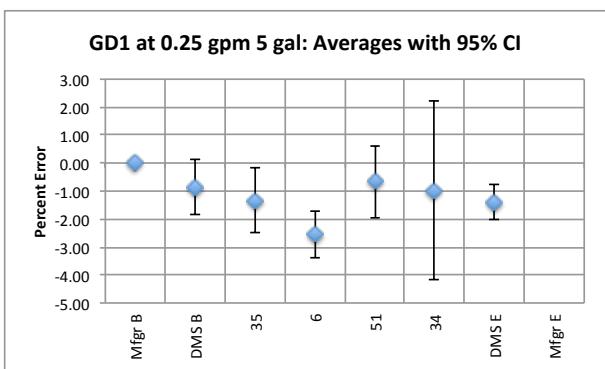
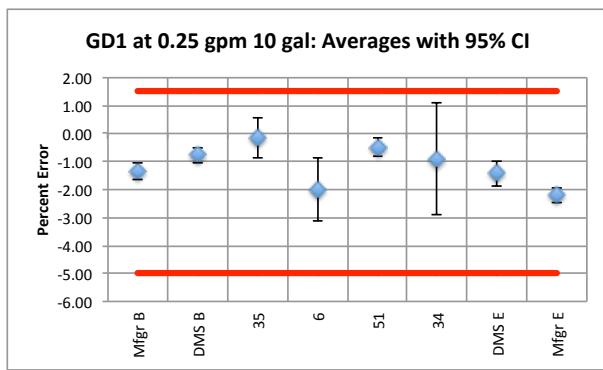
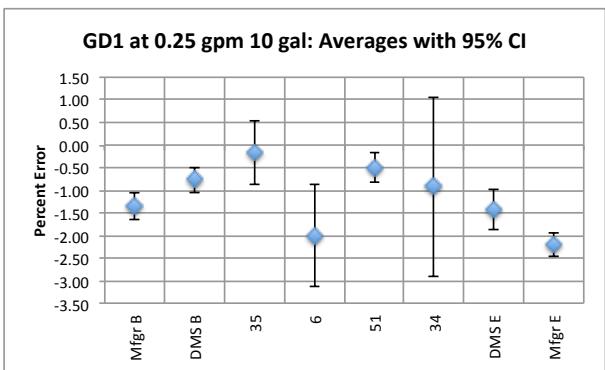
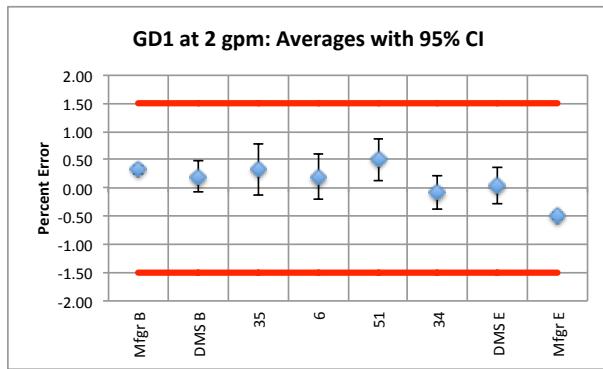
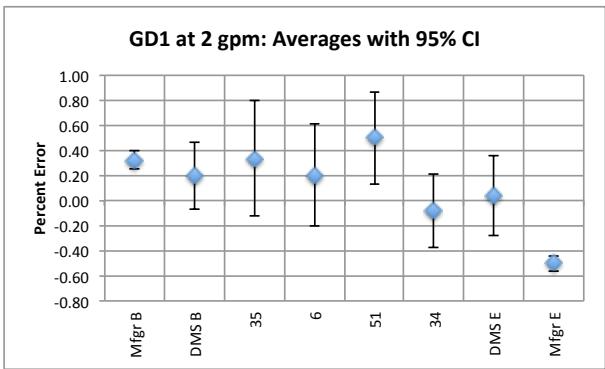
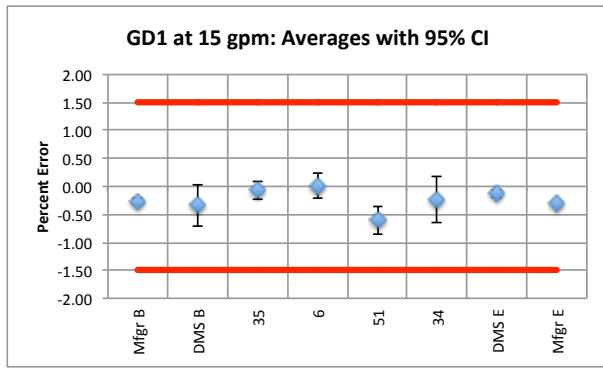
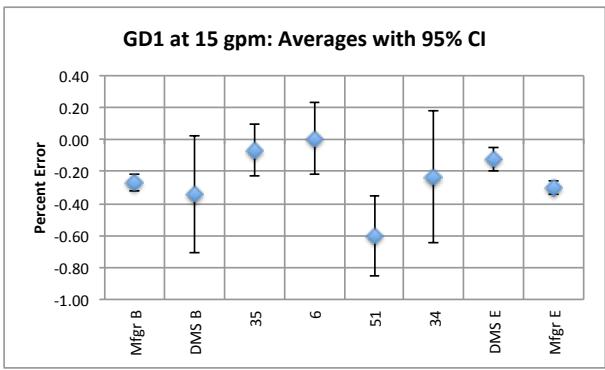


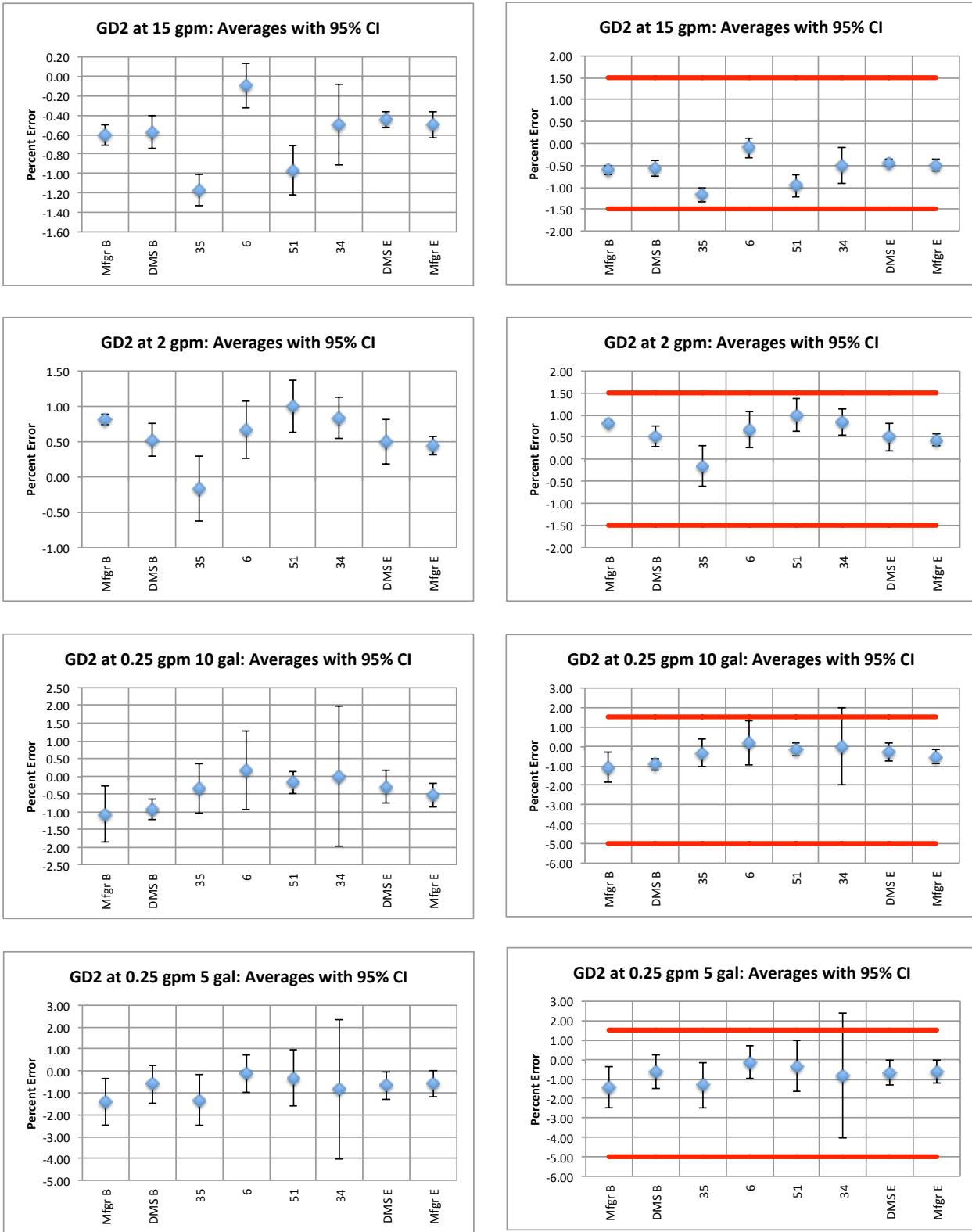


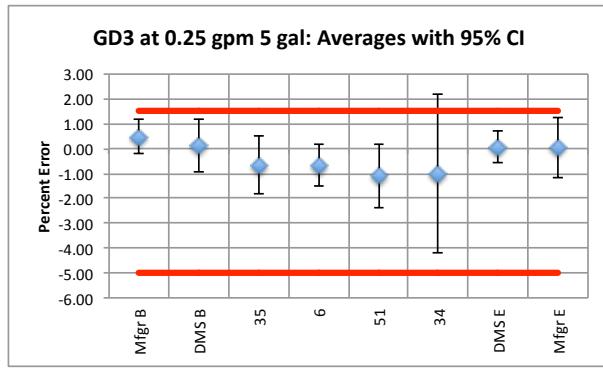
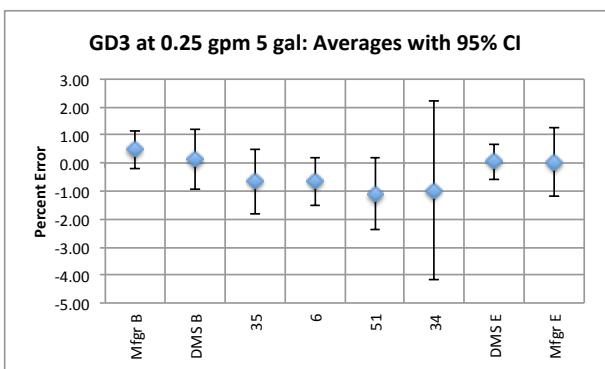
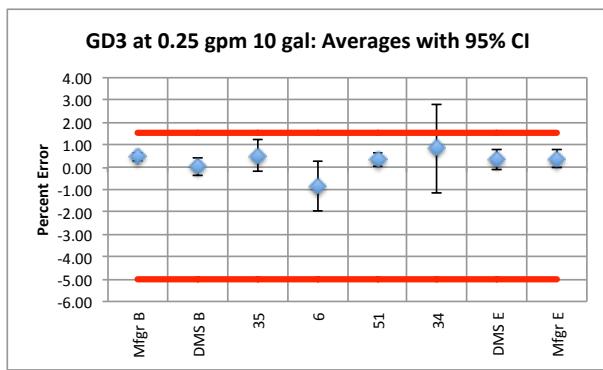
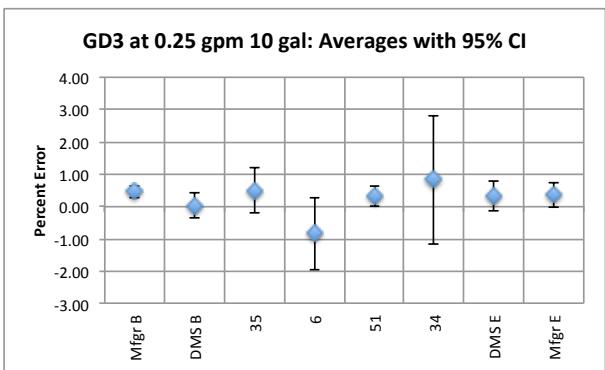
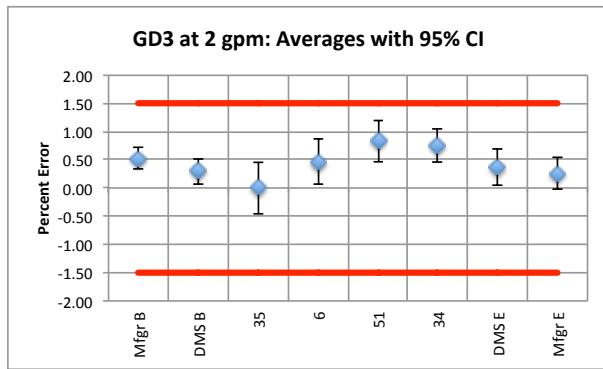
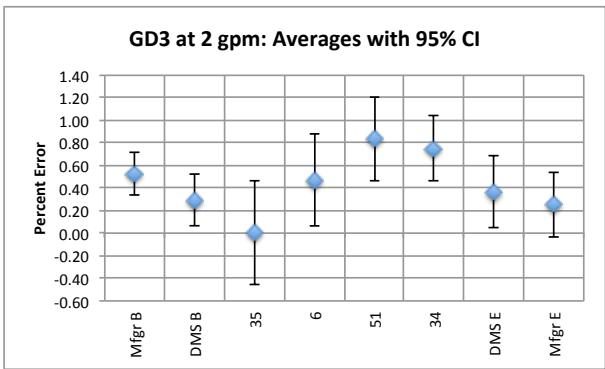
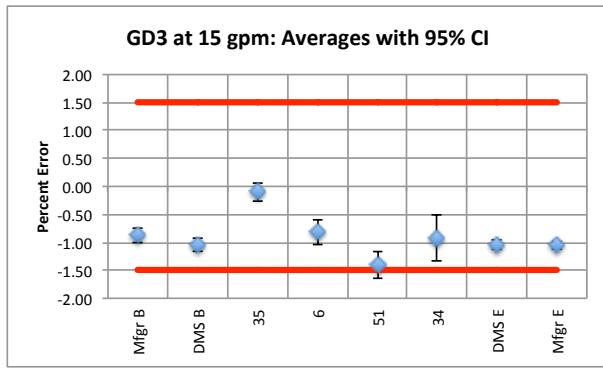
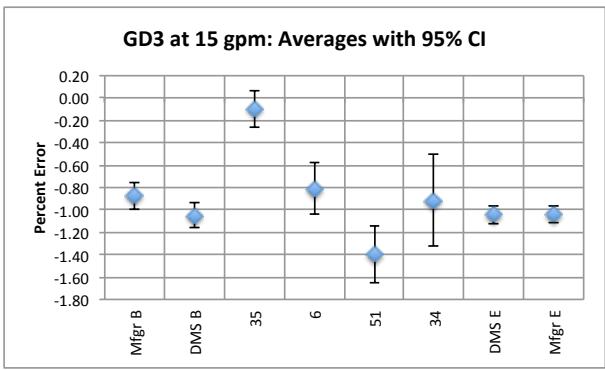


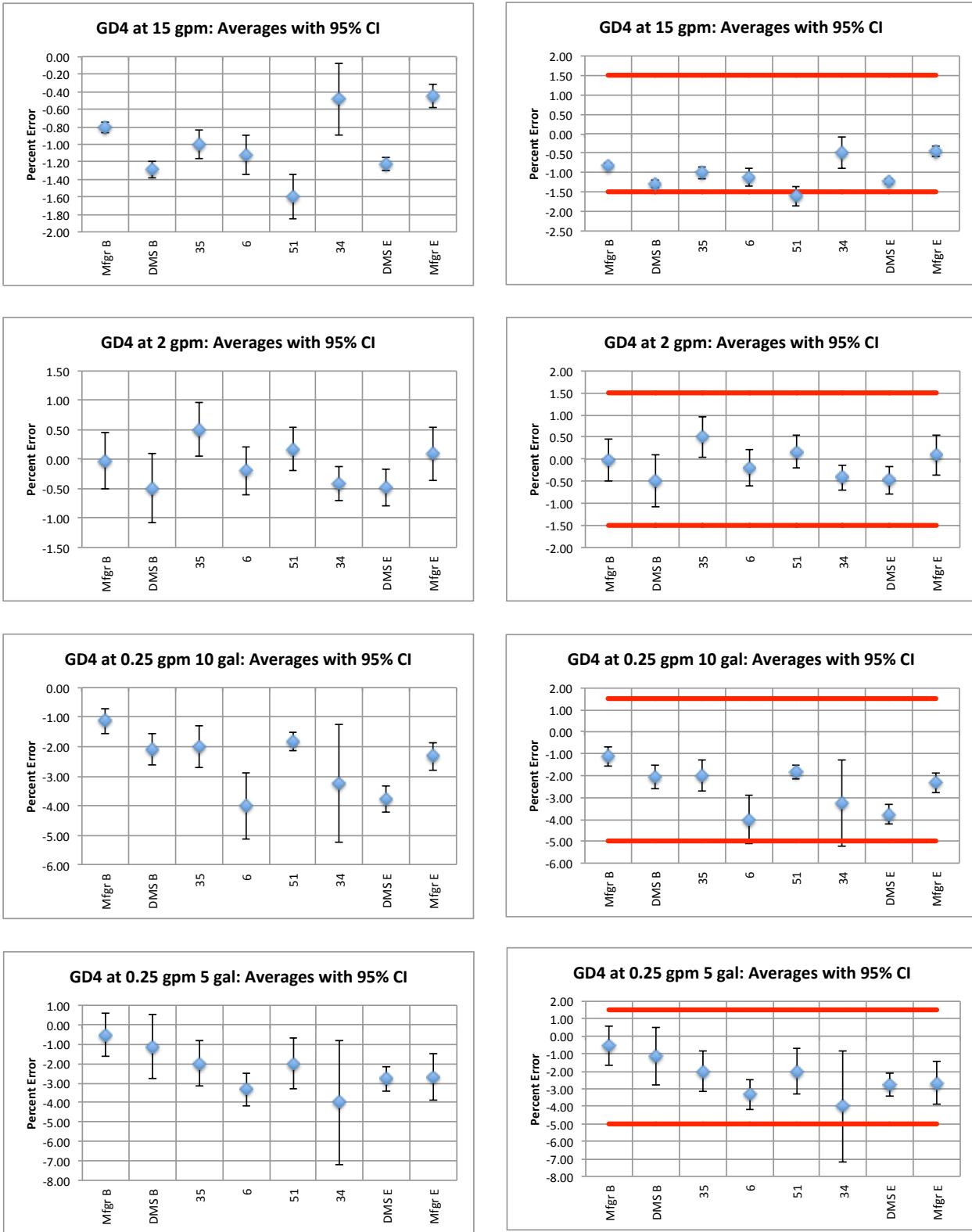


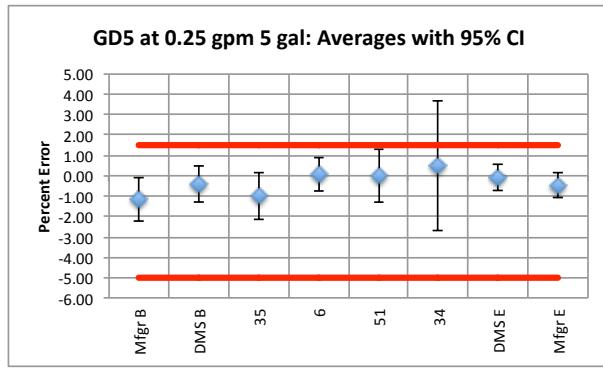
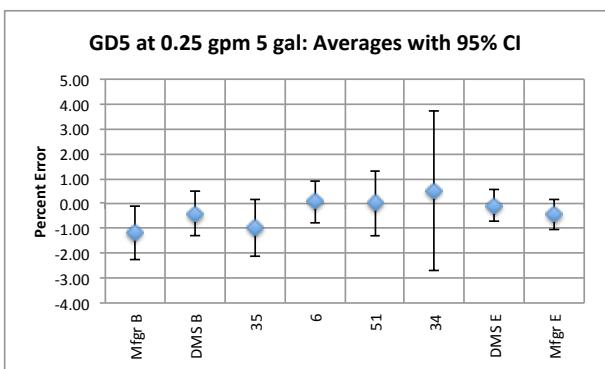
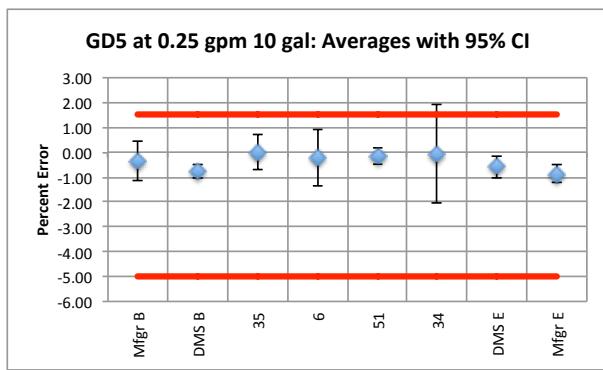
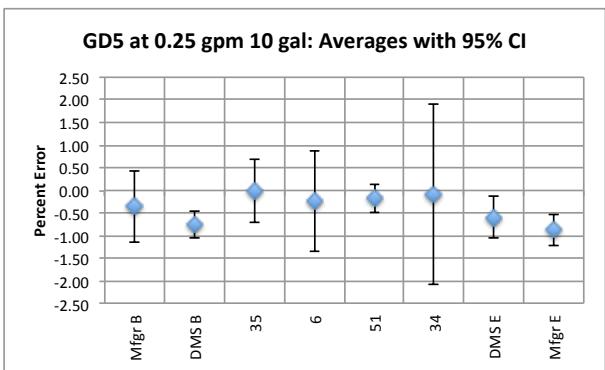
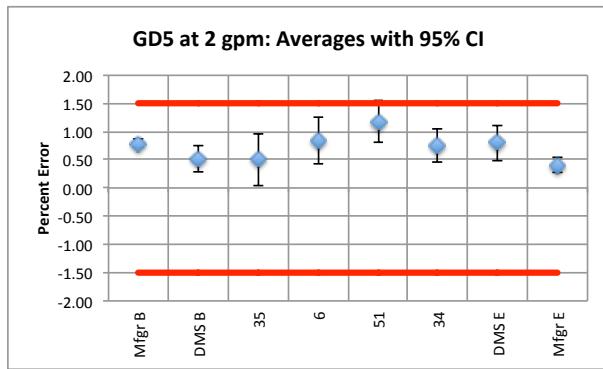
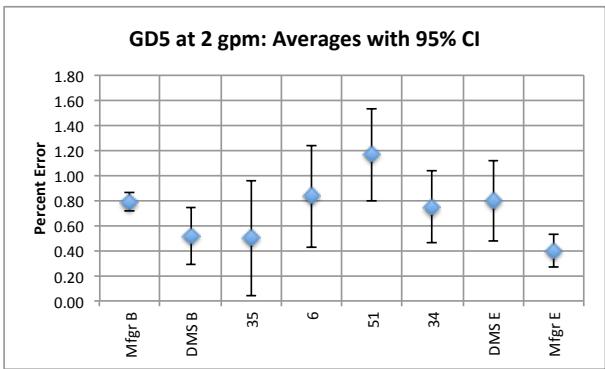
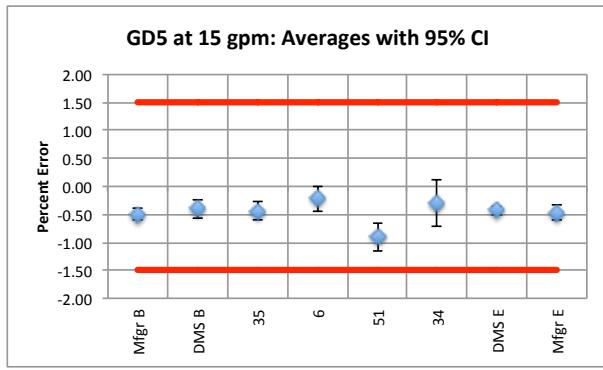
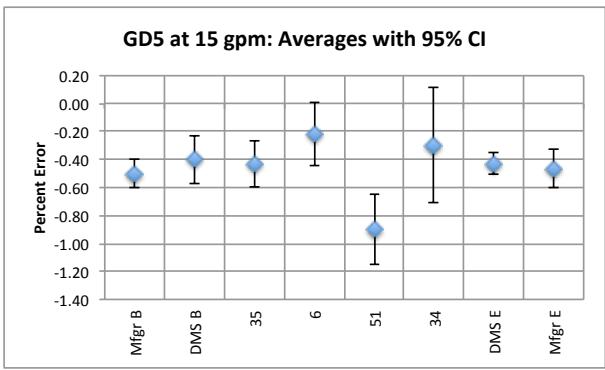








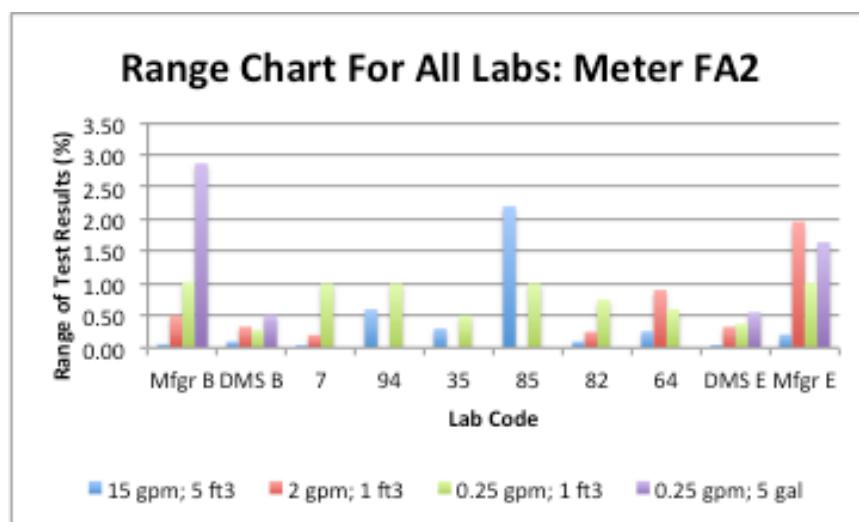
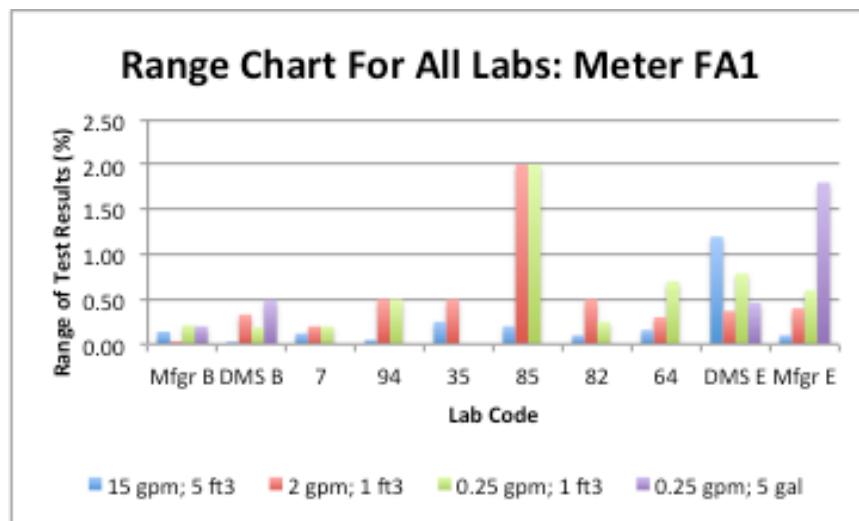




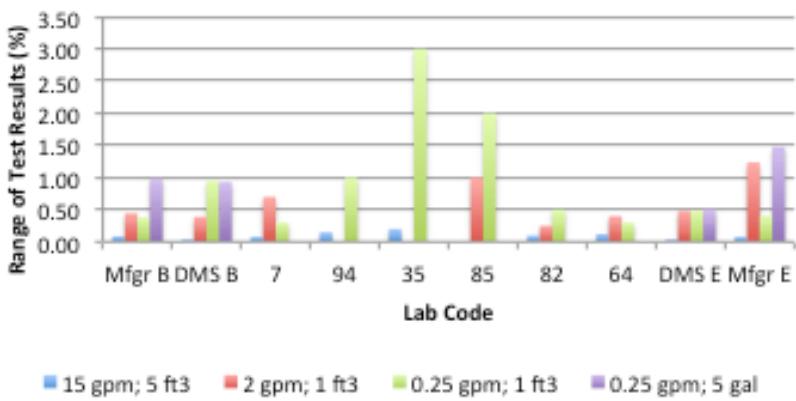
Range Charts

The following charts show the range of the three test results at each flow rate for each laboratory. The extra tests run by the manufacturers and DMS at test draft sizes different from the county laboratories are not shown. However, the range results for the manufacturers and DMS are shown for the 5-gal test draft for the meters indicating in cubic feet.

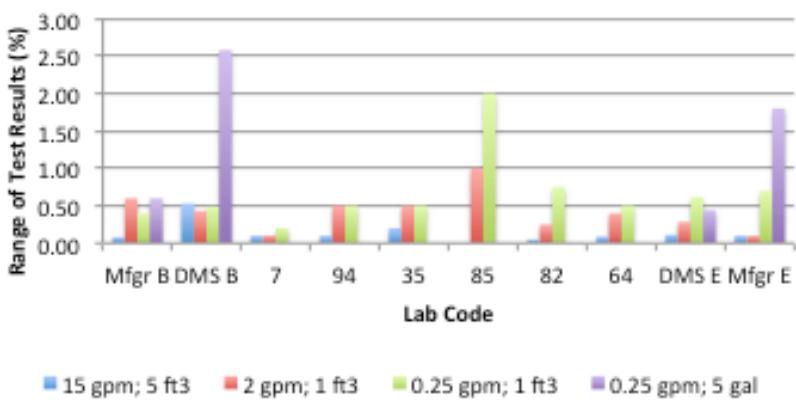
Not all labs tested all five meters in each set, so some of the total numbers of labs shown may vary for the same group of meters. In two cases, county labs tested one group of meters that indicated in gallons and one group of meters that indicated in cubic feet. Hence, two county labs may appear in a chart for one group of meters indicating in gallons and then in the chart for a group of meters indicating in cubic feet.



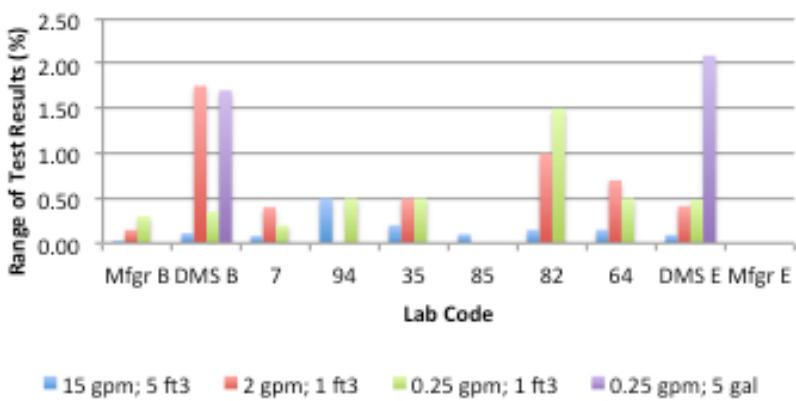
Range Chart For All Labs: Meter FA3



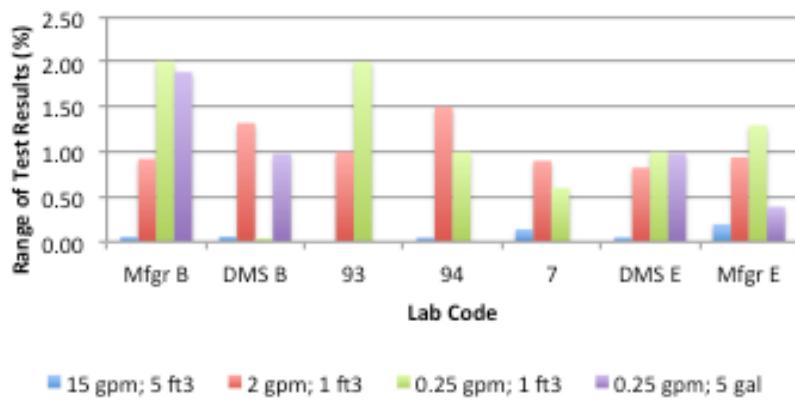
Range Chart For All Labs: Meter FA4



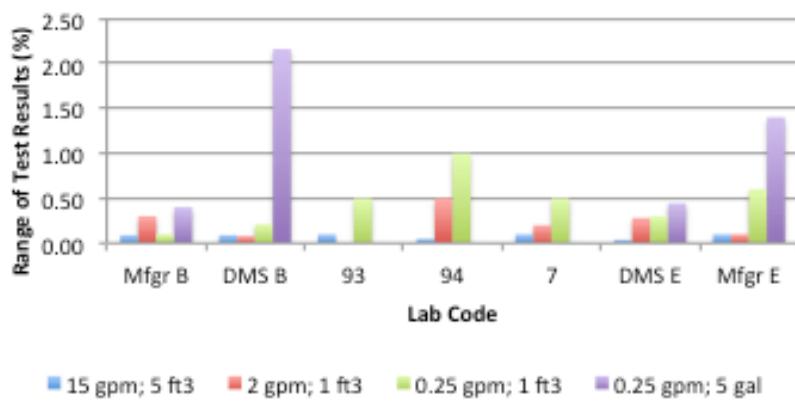
Range Chart For All Labs: Meter FA5



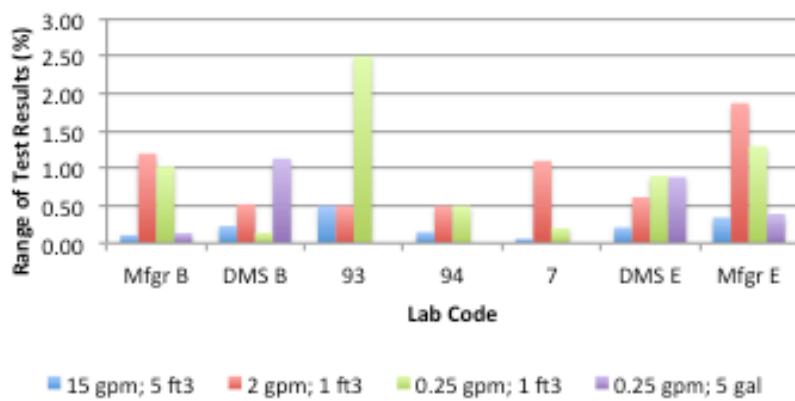
Range Chart For All Labs: Meter FB1



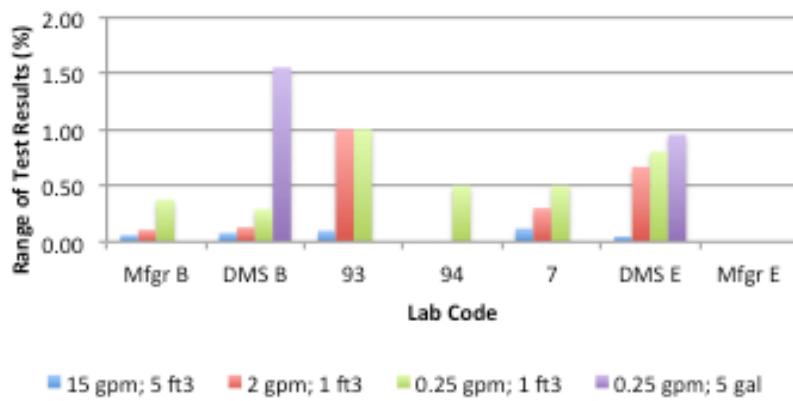
Range Chart For All Labs: Meter FB2



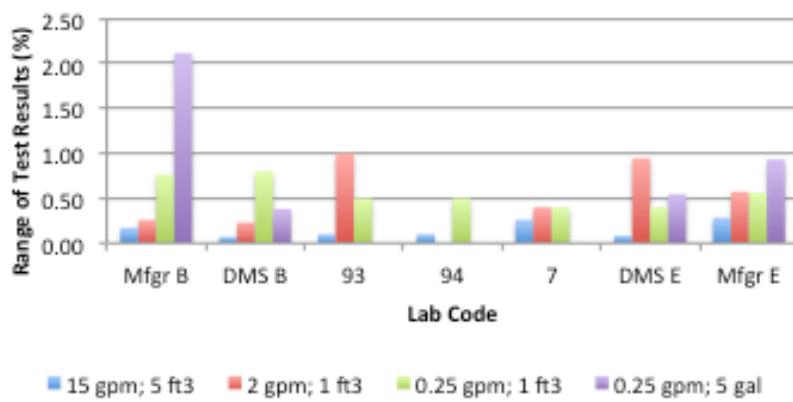
Range Chart For All Labs: Meter FB3



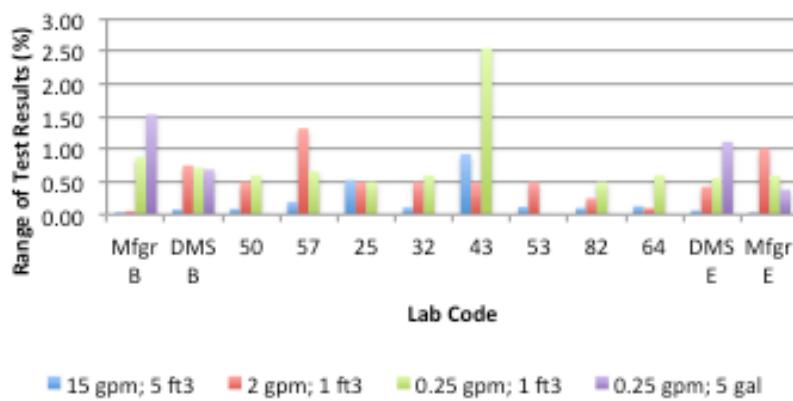
Range Chart For All Labs: Meter FB4



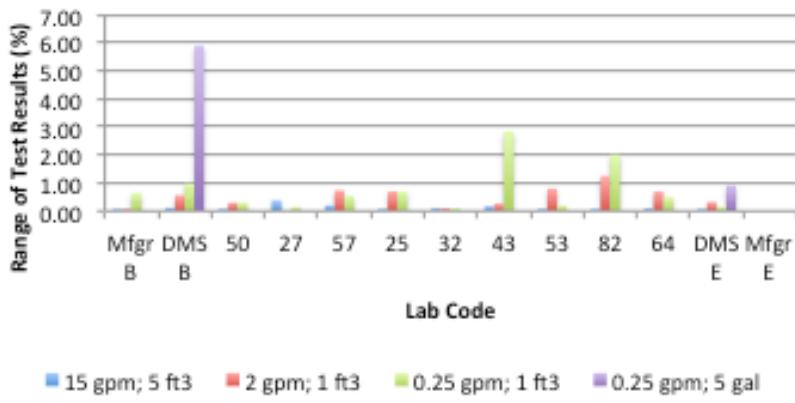
Range Chart For All Labs: Meter FB5



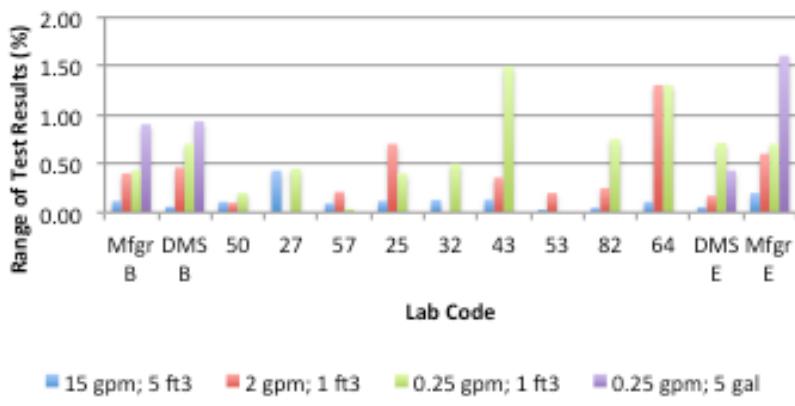
Range Chart For All Labs: Meter FC1



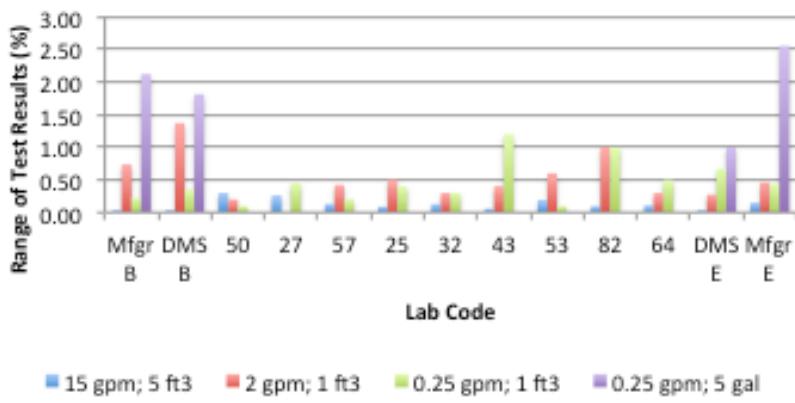
Range Chart For All Labs: Meter FC2



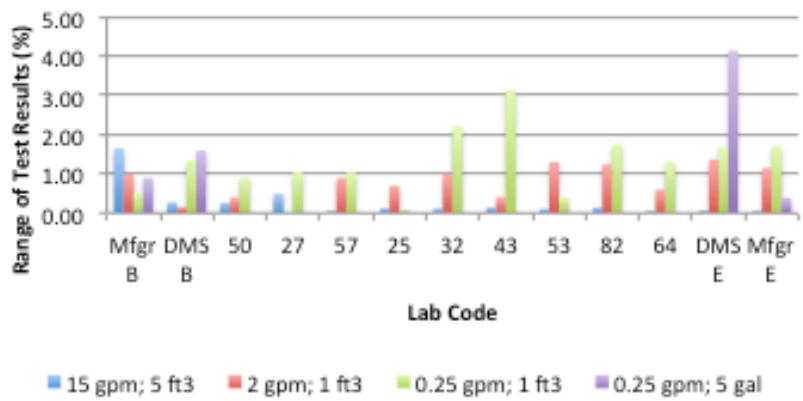
Range Chart For All Labs: Meter FC3



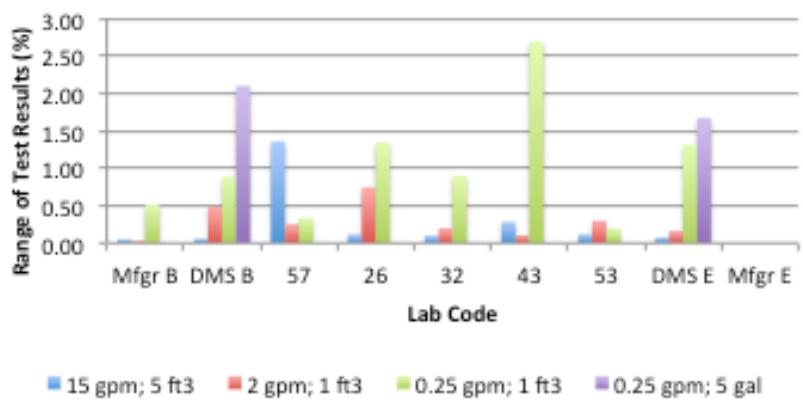
Range Chart For All Labs: Meter FC4



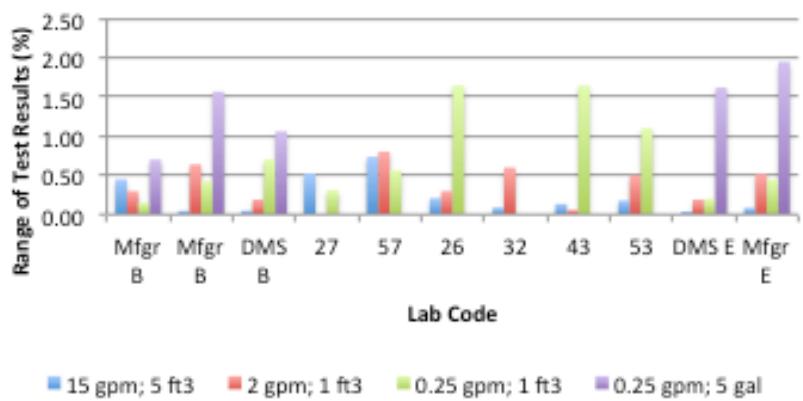
Range Chart For All Labs: Meter FC5



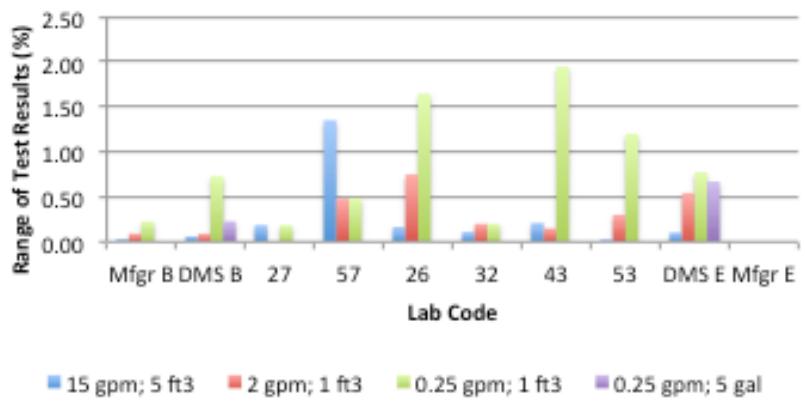
Range Chart For All Labs: Meter FD1



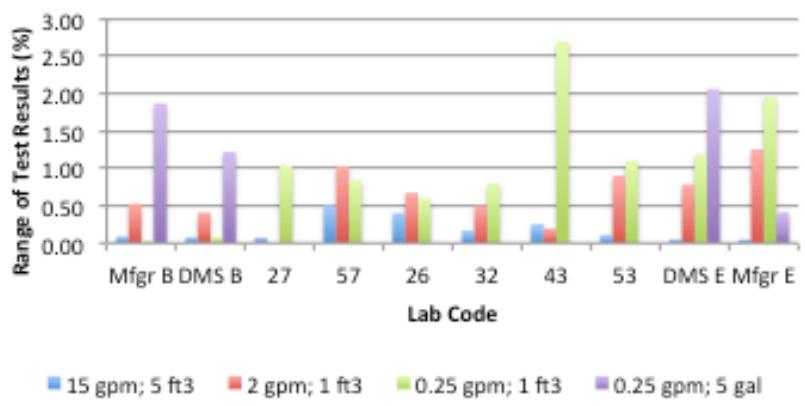
Range Chart For All Labs: Meter FD2



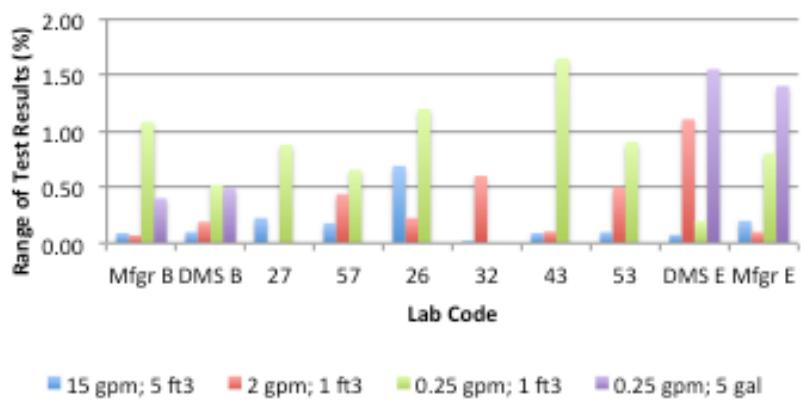
Range Chart For All Labs: Meter FD3



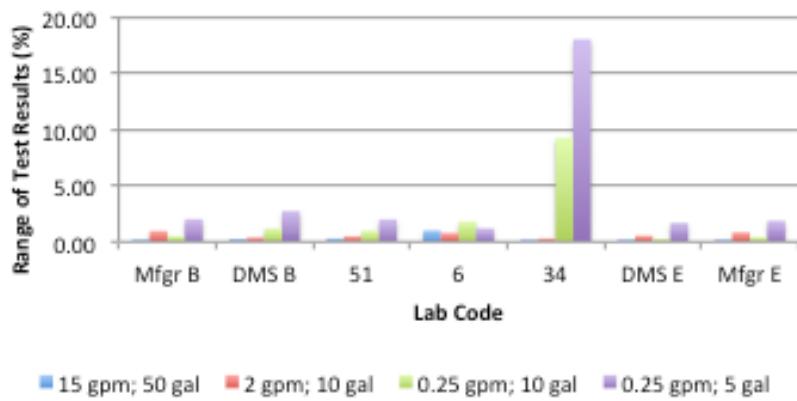
Range Chart For All Labs: Meter FD4



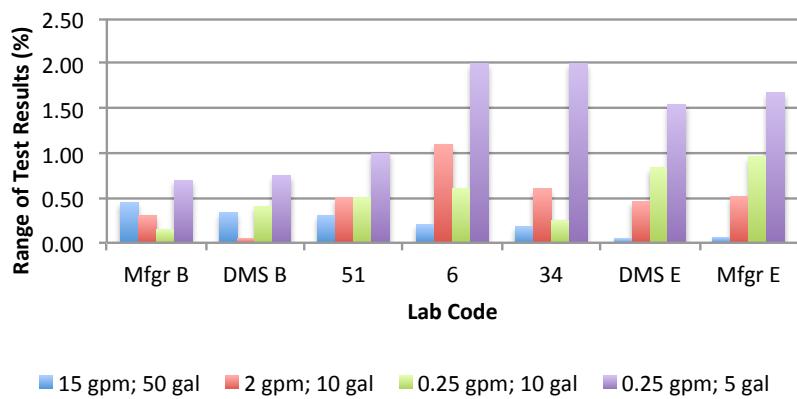
Range Chart For All Labs: Meter FD5



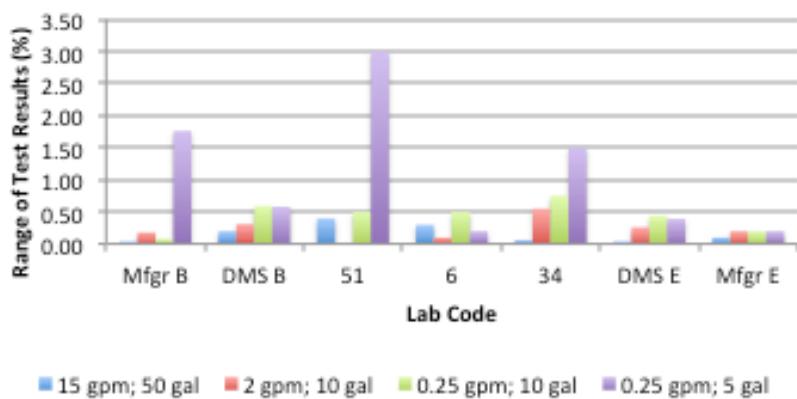
Range Chart For All Labs: Meter GA1



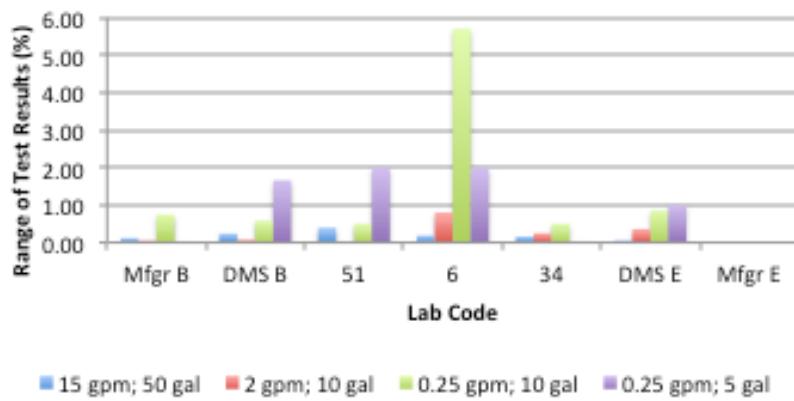
Range Chart For All Labs: Meter GA2



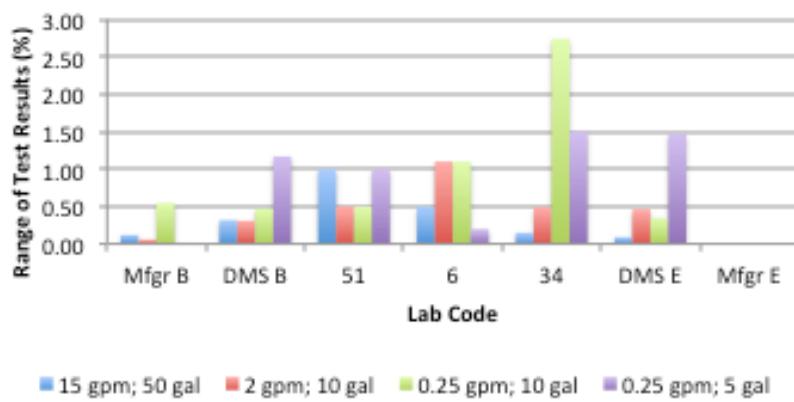
Range Chart For All Labs: Meter GA3



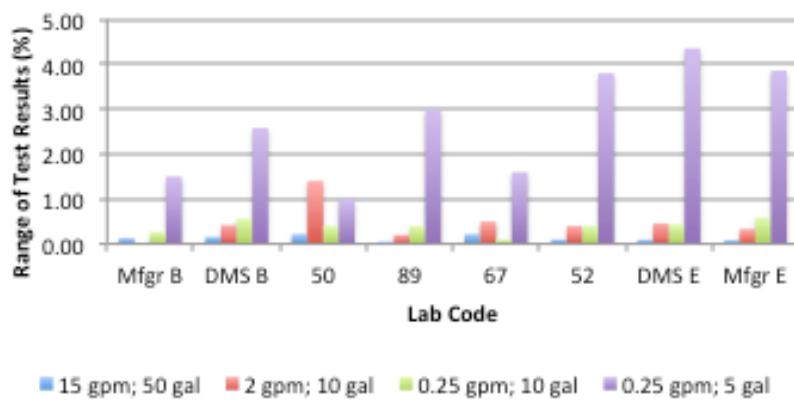
Range Chart For All Labs: Meter GA4



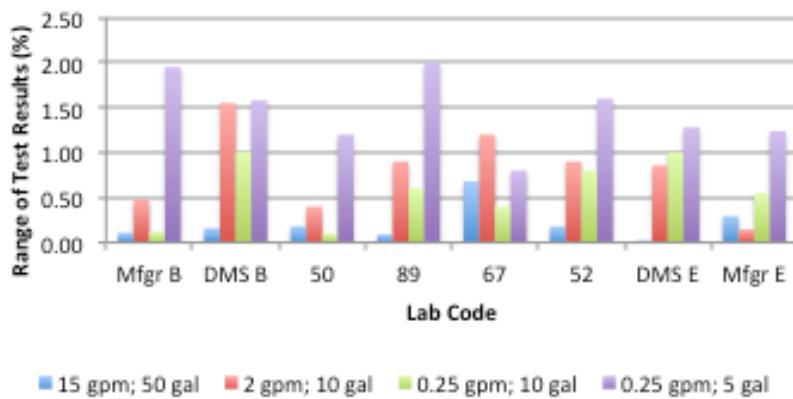
Range Chart For All Labs: Meter GA5



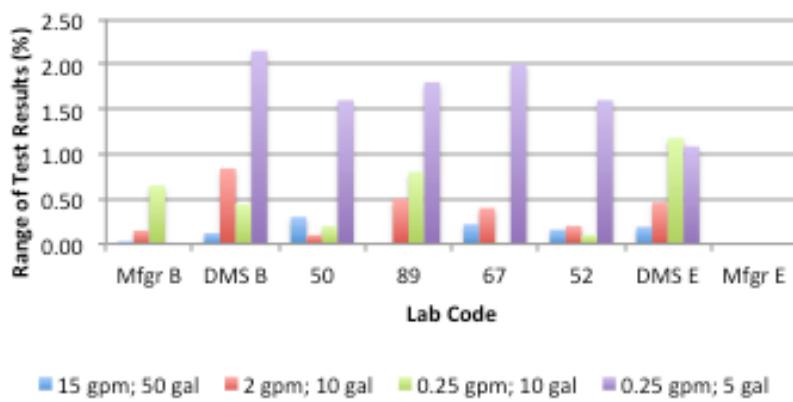
Range Chart For All Labs: Meter GB1



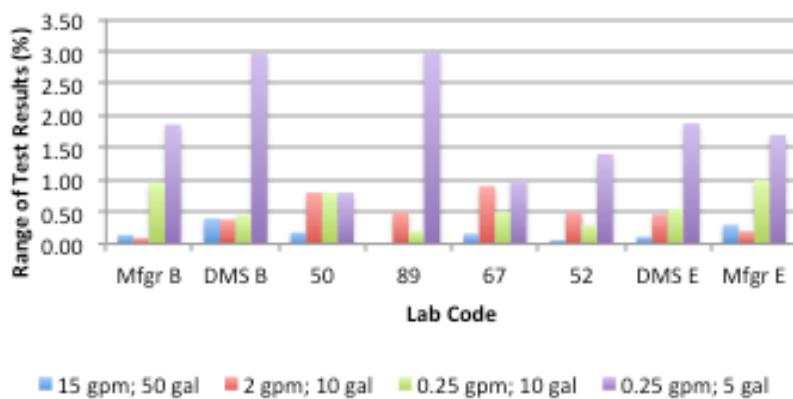
Range Chart For All Labs: Meter GB2



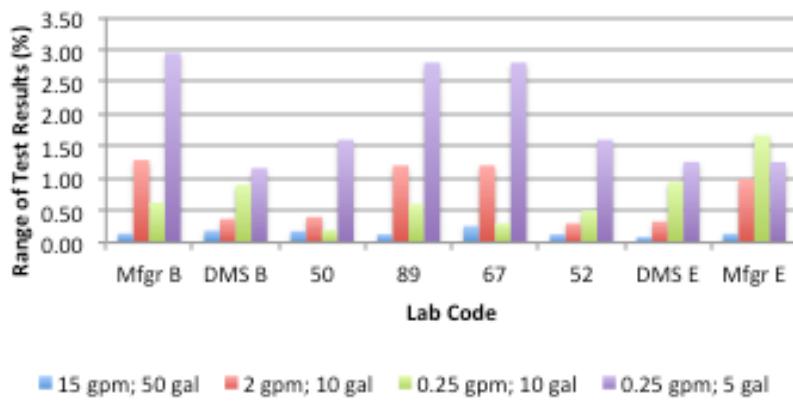
Range Chart For All Labs: Meter GB3



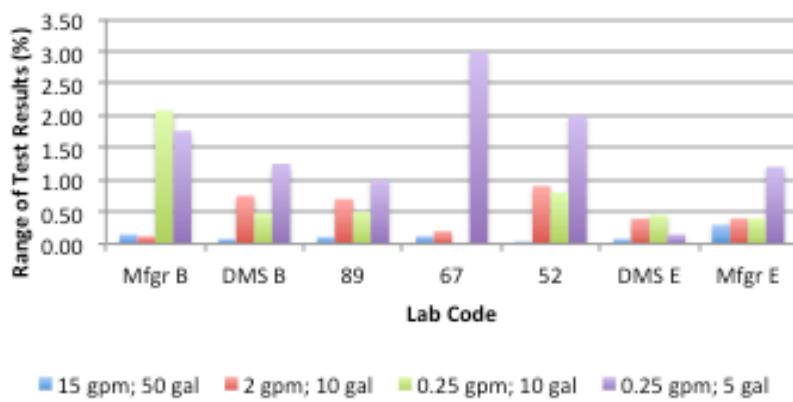
Range Chart For All Labs: Meter GB4



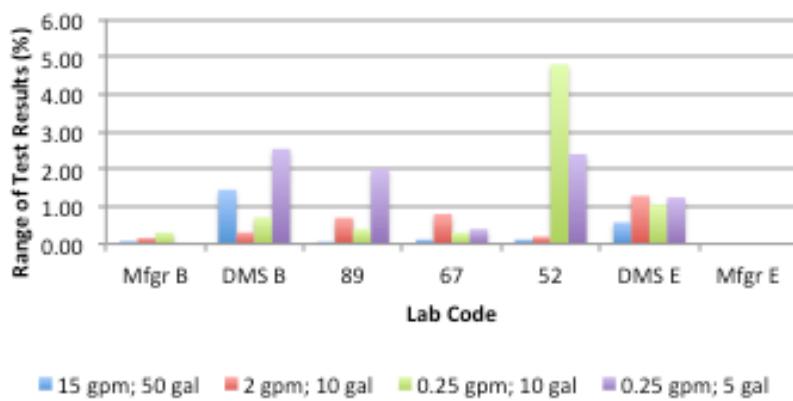
Range Chart For All Labs: Meter GB5



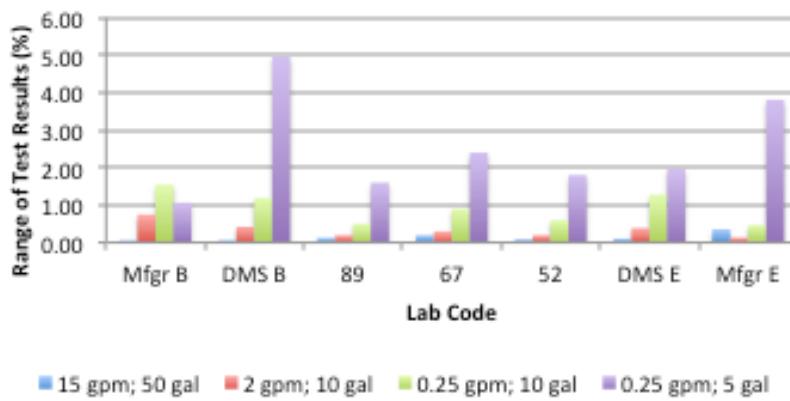
Range Chart For All Labs: Meter GC1



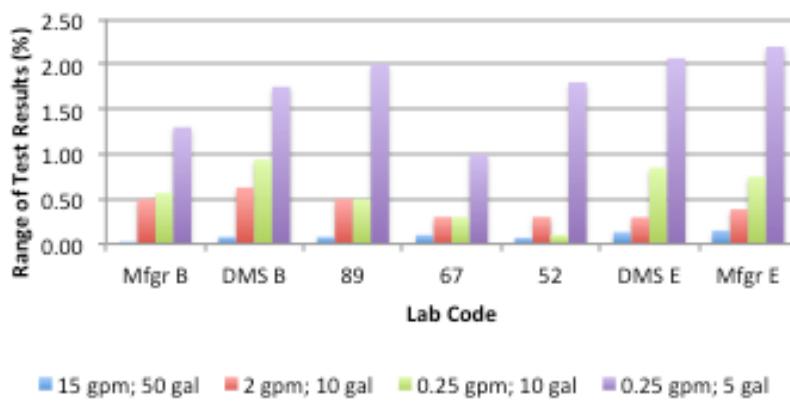
Range Chart For All Labs: Meter GC2



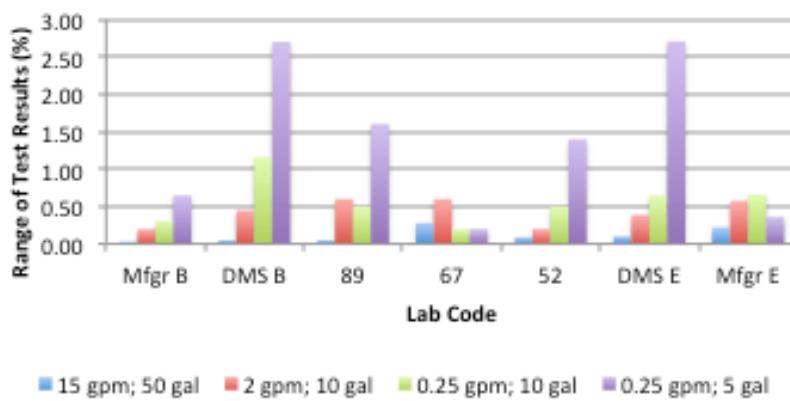
Range Chart For All Labs: Meter GC3



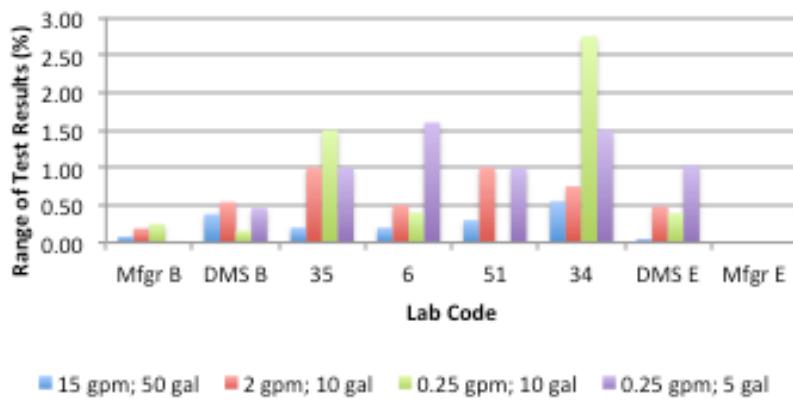
Range Chart For All Labs: Meter GC4



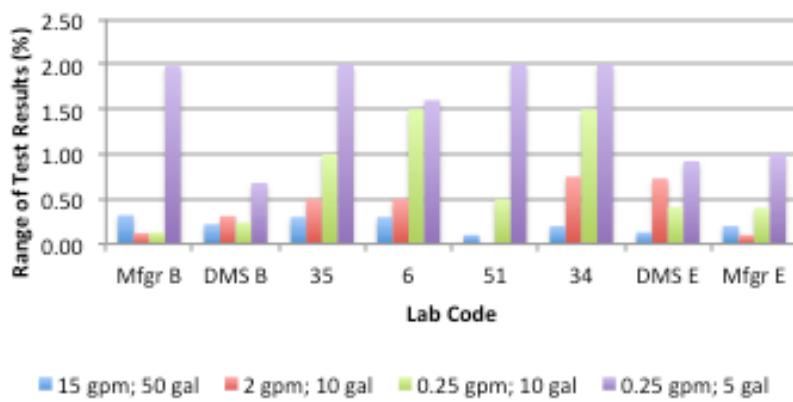
Range Chart For All Labs: Meter GC5



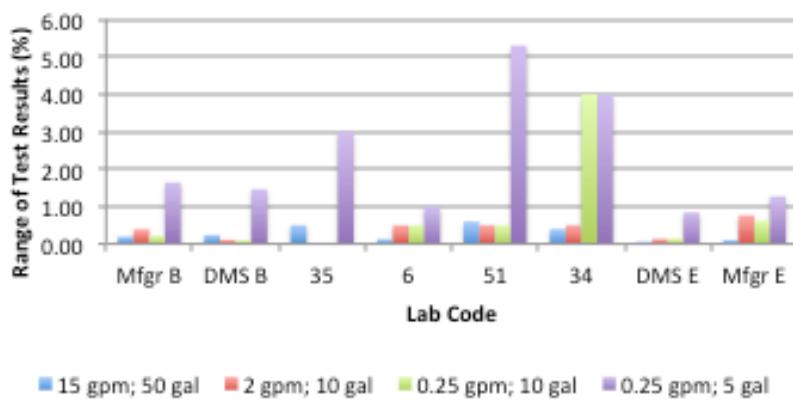
Range Chart For All Labs: Meter GD1



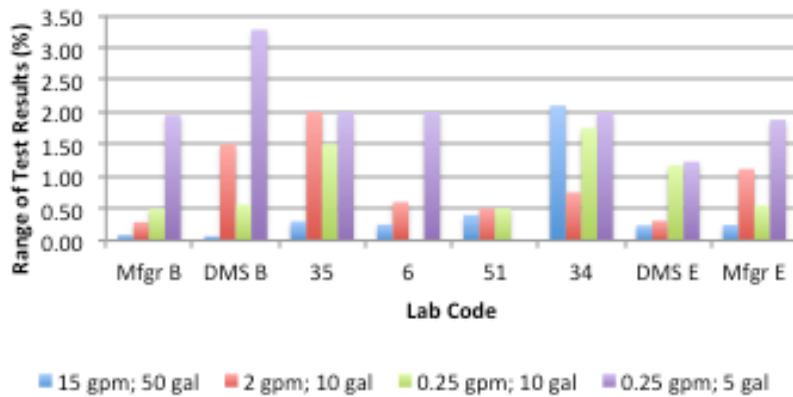
Range Chart For All Labs: Meter GD2



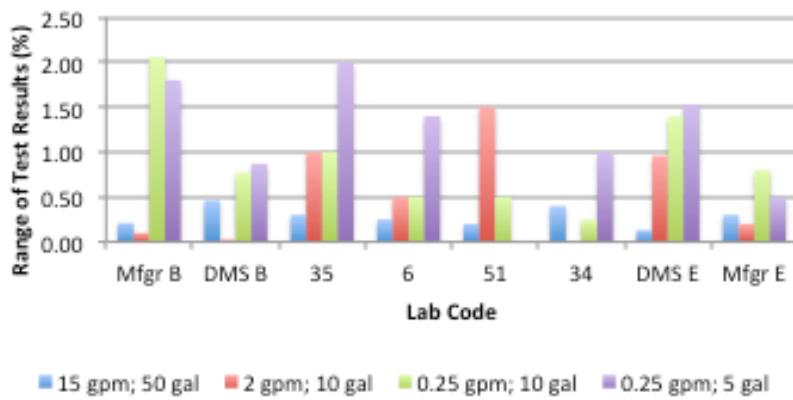
Range Chart For All Labs: Meter GD3



Range Chart For All Labs: Meter GD4



Range Chart For All Labs: Meter GD5

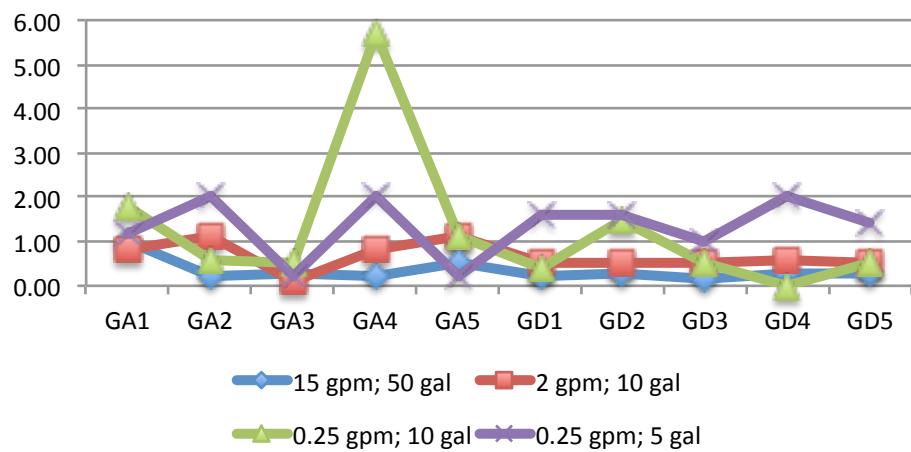


Range Charts of Test Results by Test Laboratory

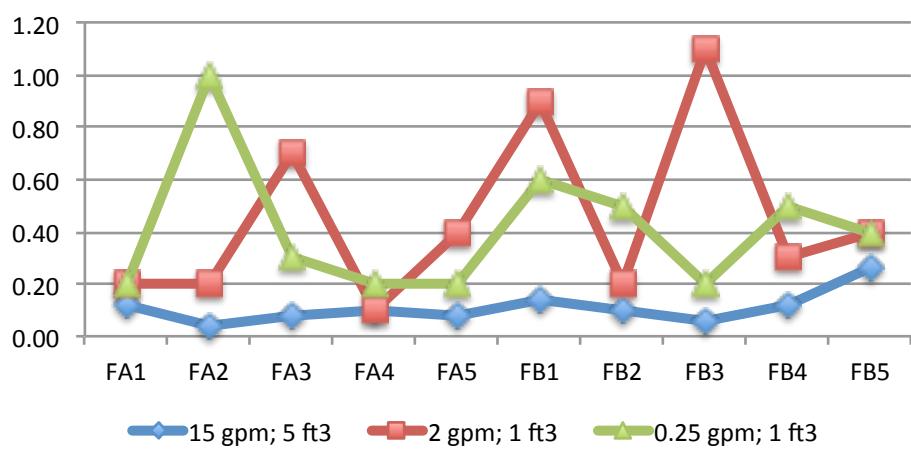
Below are charts of the range in the individual test results for each laboratory for the group or groups of meters tested. The county charts are presented first, followed by the DMS results, and then the manufacturers' results are presented. The test drafts and flow rates that are common for all of the labs are shown on each chart, i.e., 15 gpm, 2 gpm, and 0.25 gpm for 1 ft³ or 10 gal and 5 gal. Laboratories 35 and 50 tested one group of meters indicating in gallons and one group of meters indicating in cubic feet.

The values for the y-axis are the range in percent of meter error.

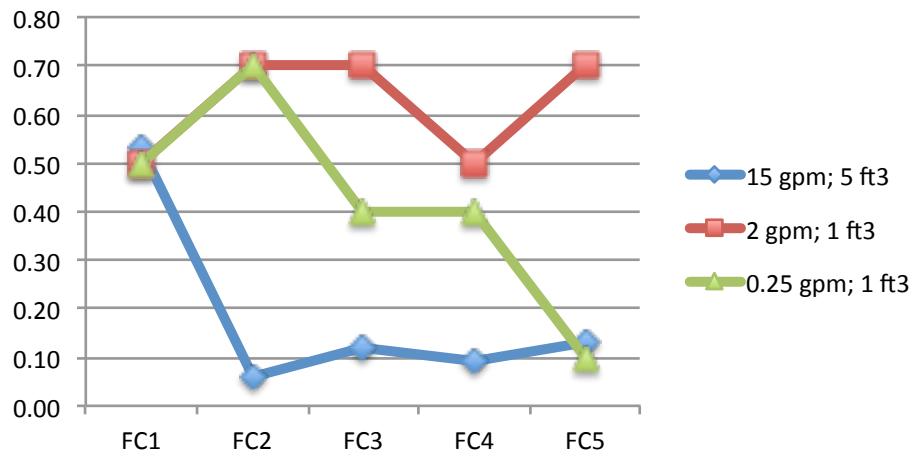
Range Chart for All Meters: Lab 6



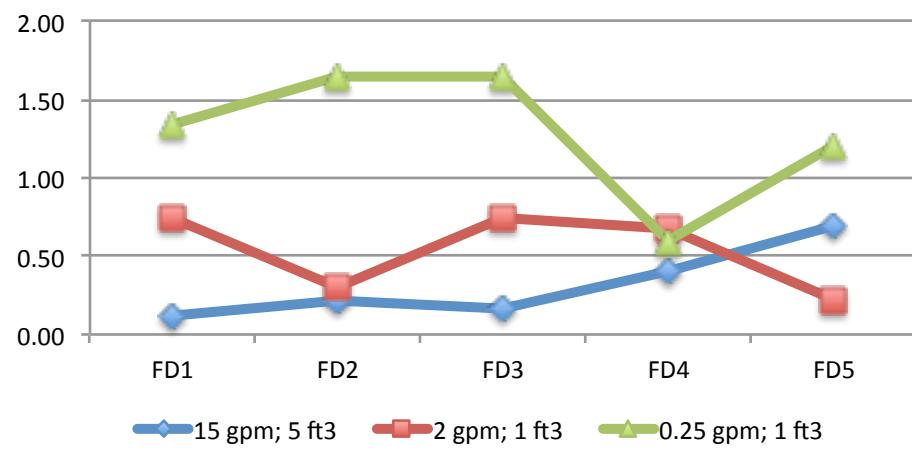
Range Chart for All Meters: Lab 7



Range Chart for All Meters: Lab 25

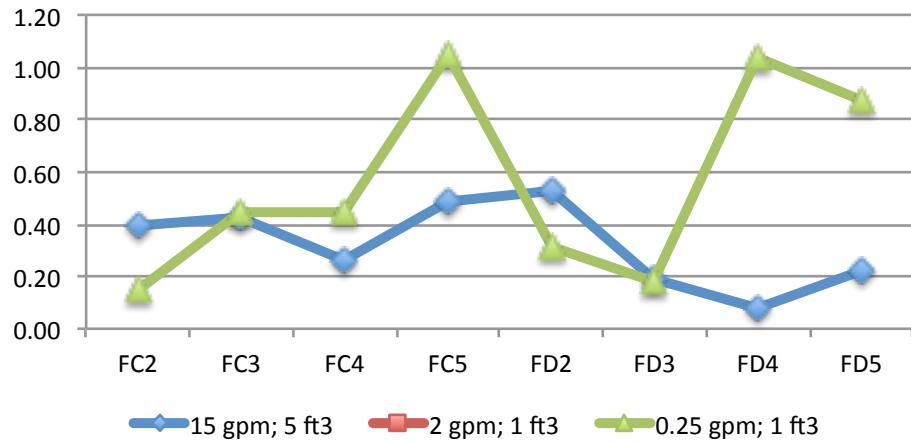


Range Chart for All Meters: Lab 26

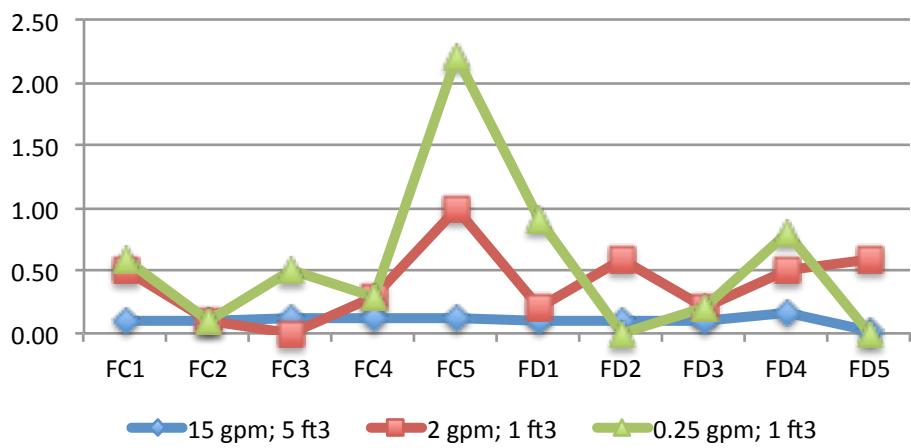


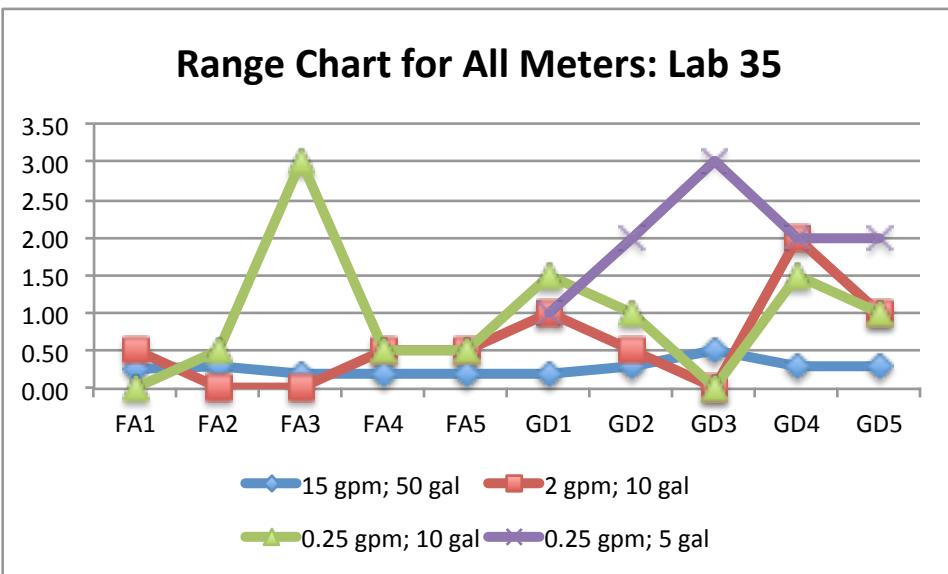
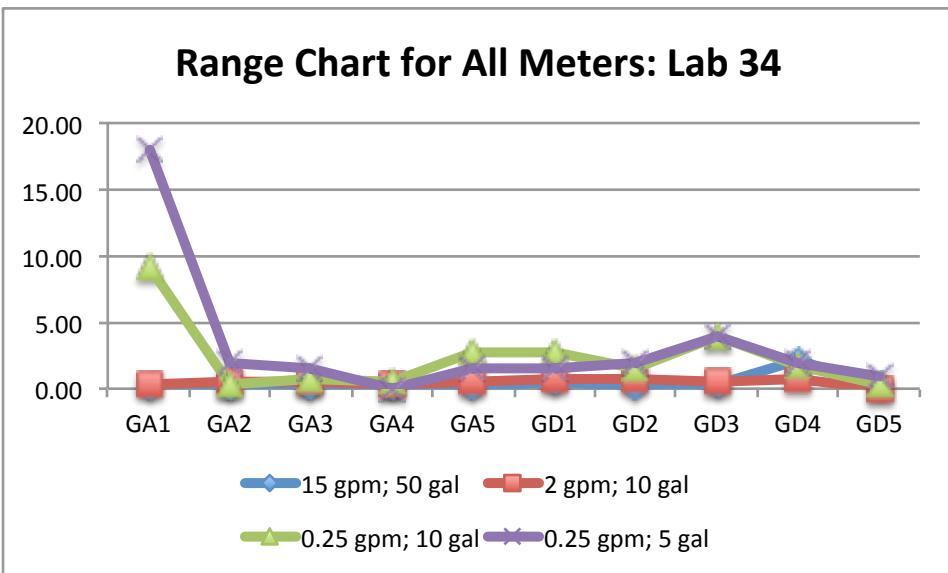
Laboratory 27 tested four meters from each set and did not run any tests at 2 gpm.

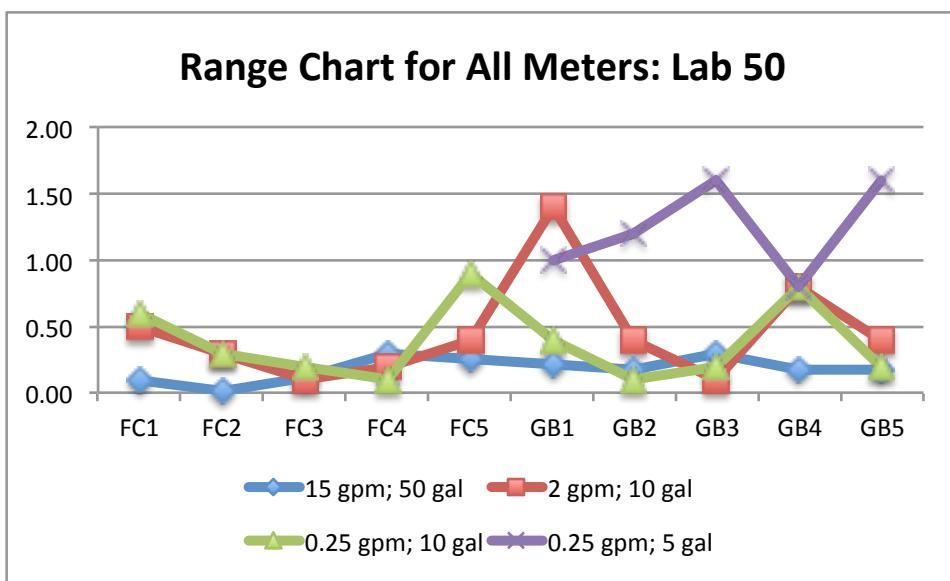
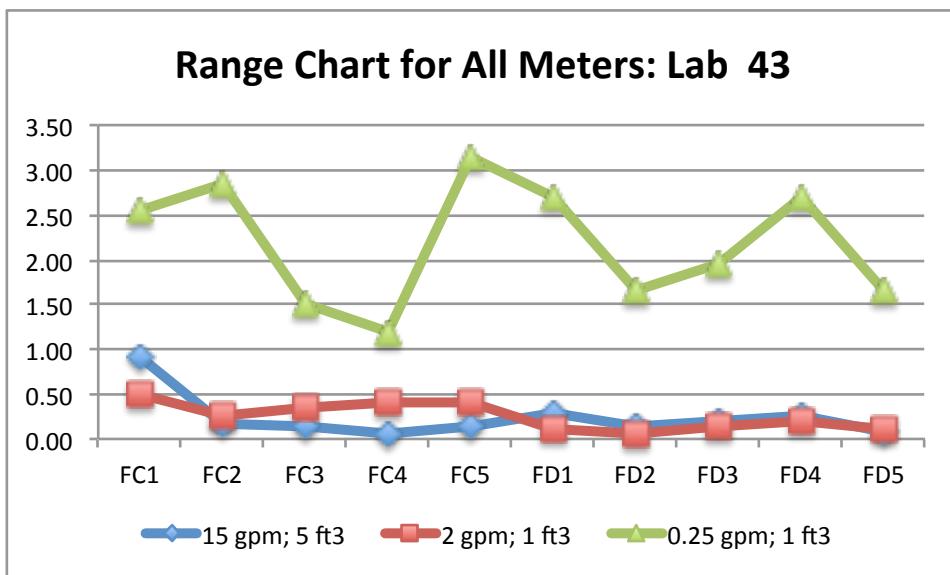
Range Chart for All Meters: Lab 27



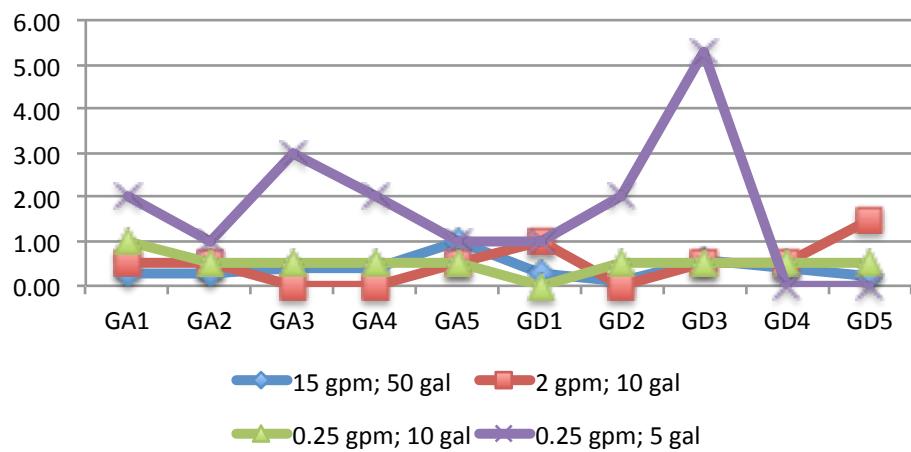
Range Chart for All Meters: Lab 32



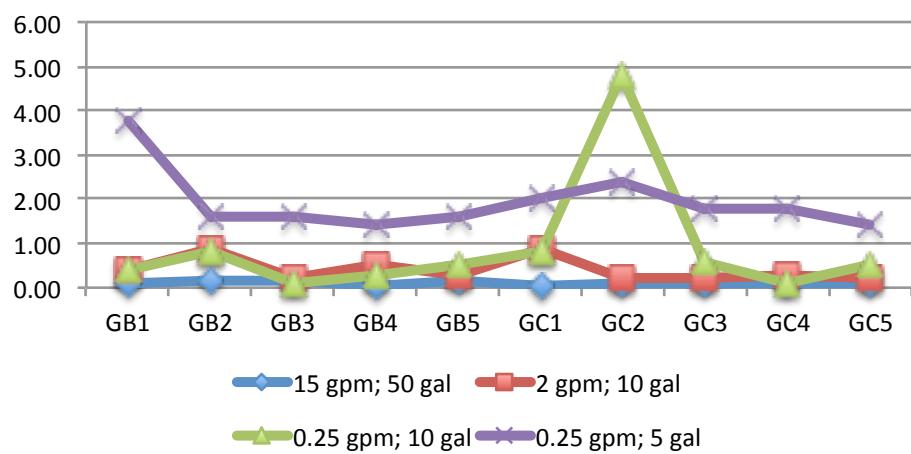




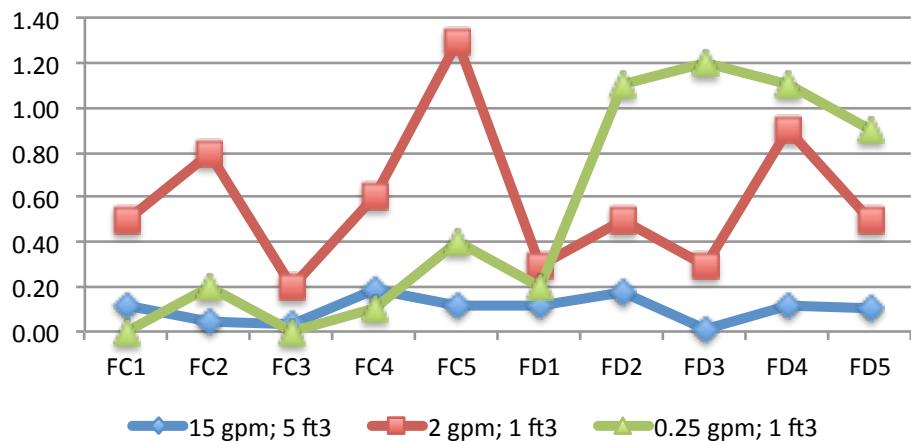
Range Chart for All Meters: Lab 51



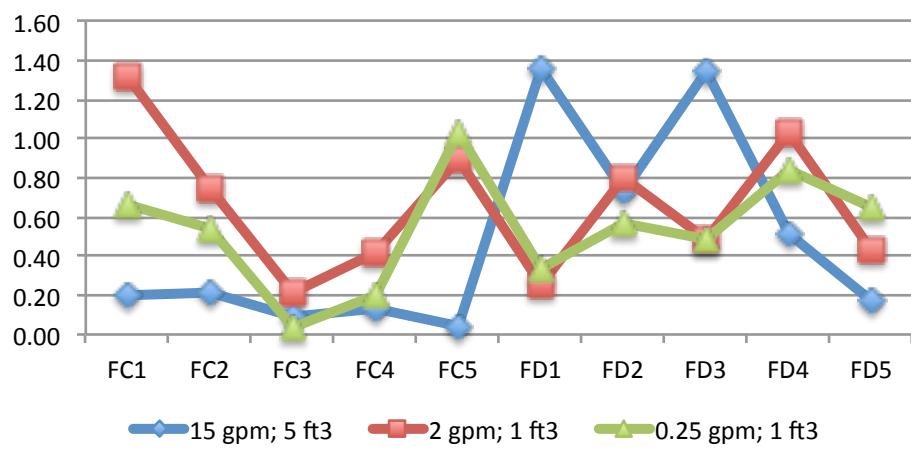
Range Chart for All Meters: Lab 52

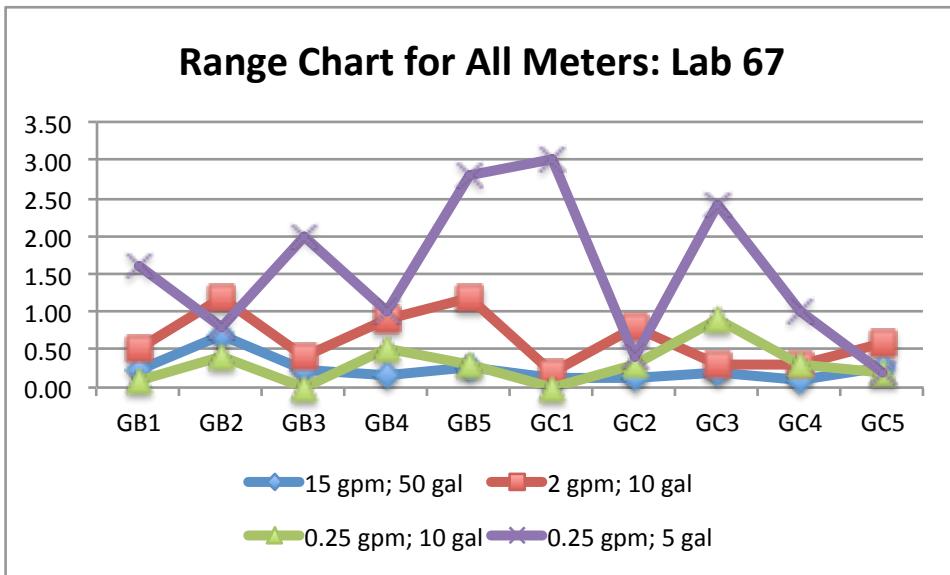
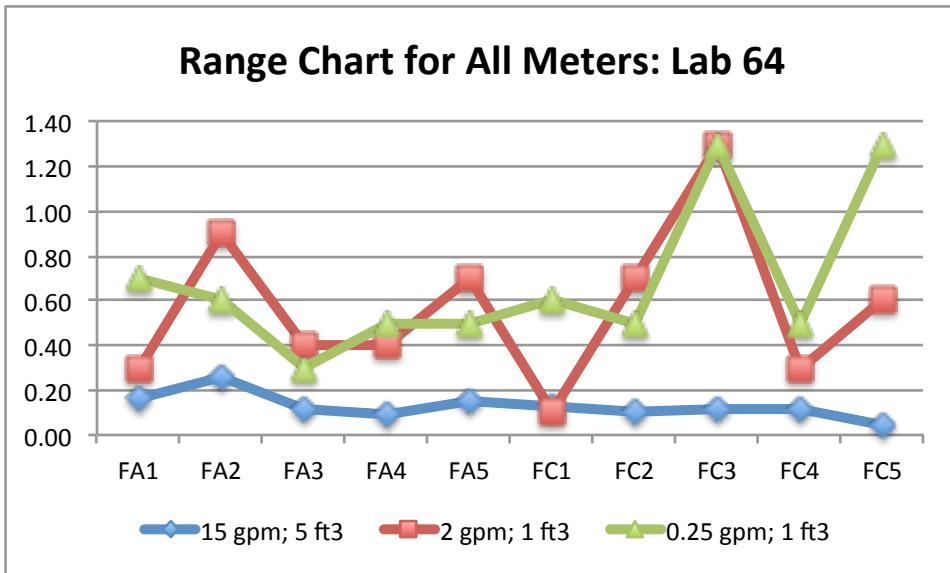


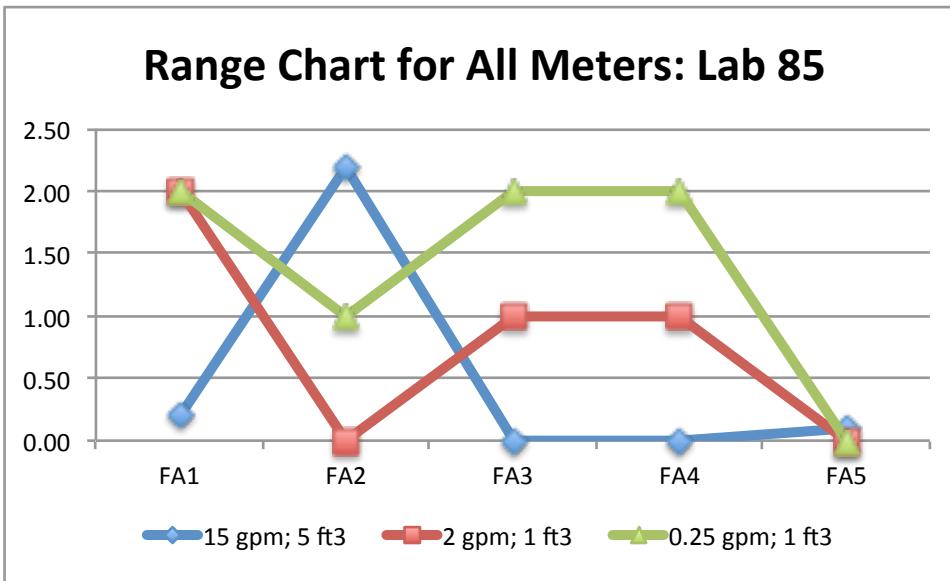
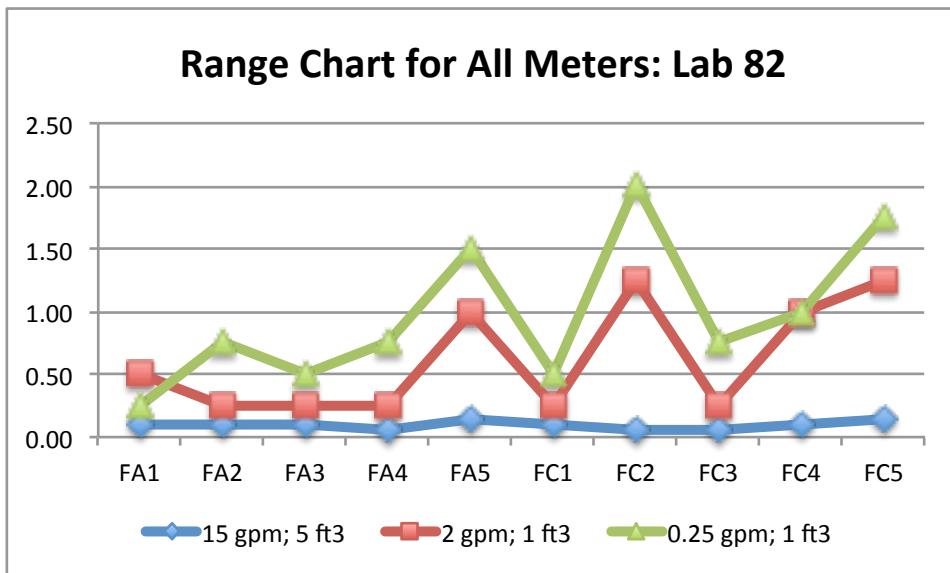
Range Chart for All Meters: Lab 53

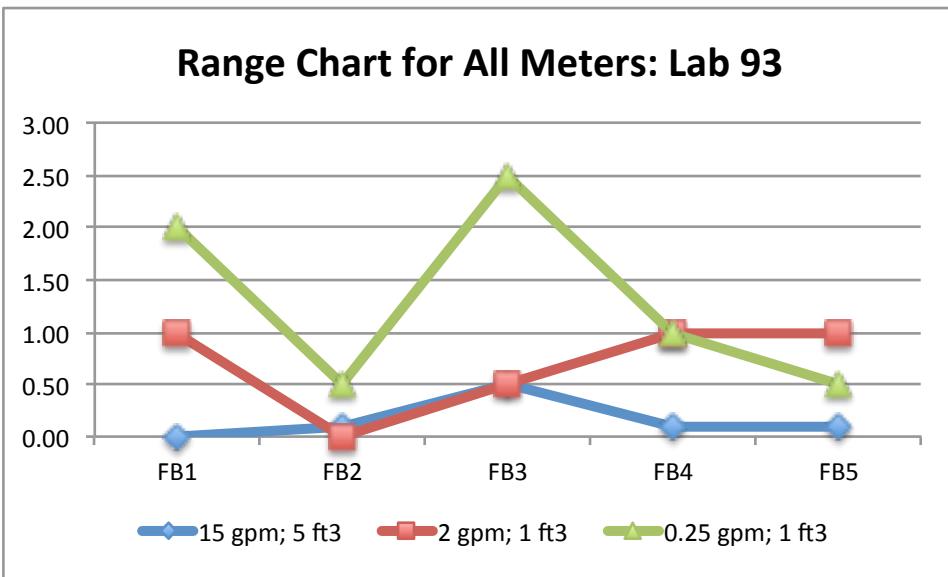
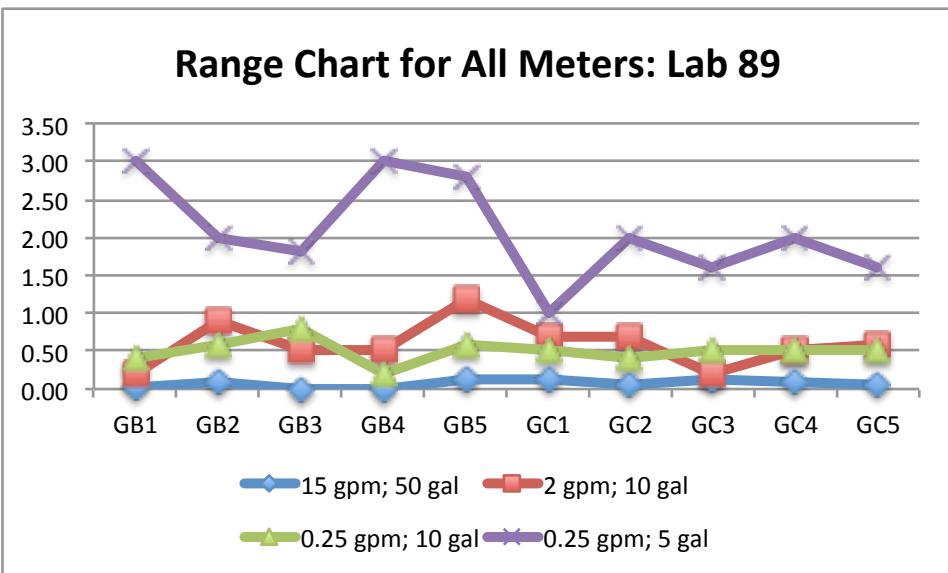


Range Chart for All Meters: Lab 57

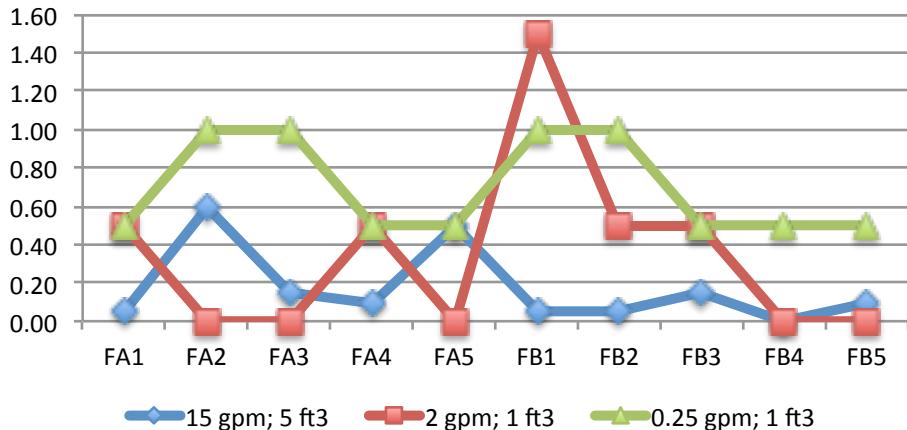






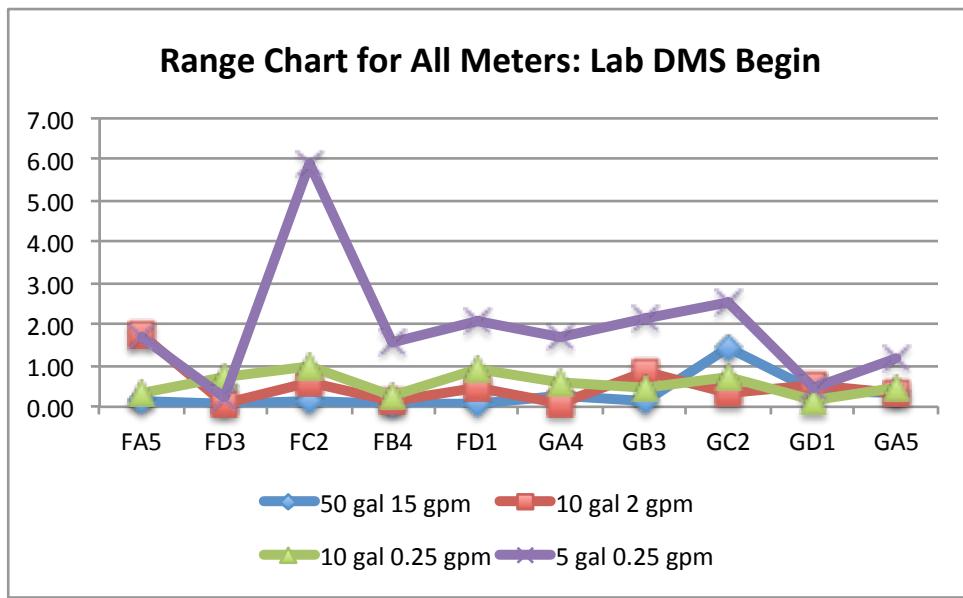
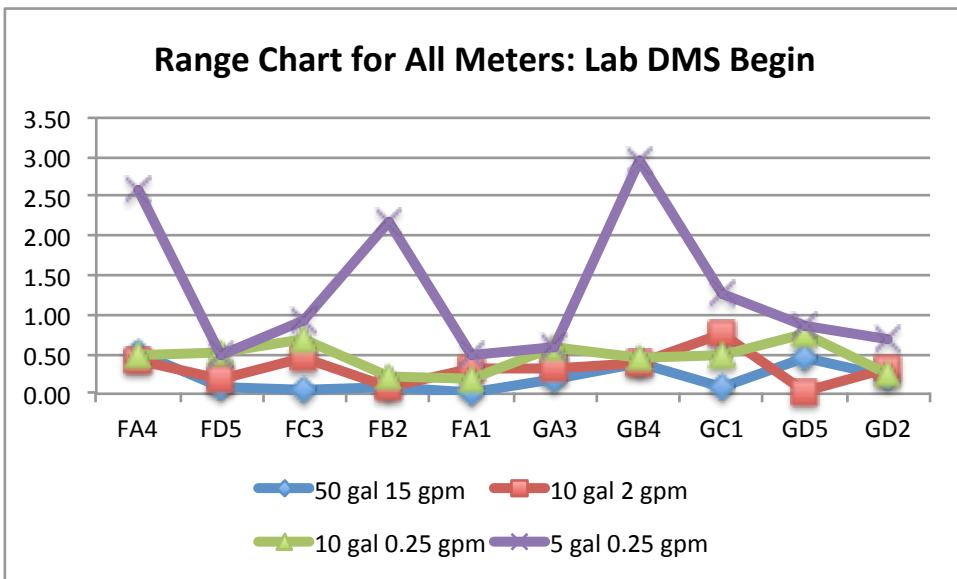


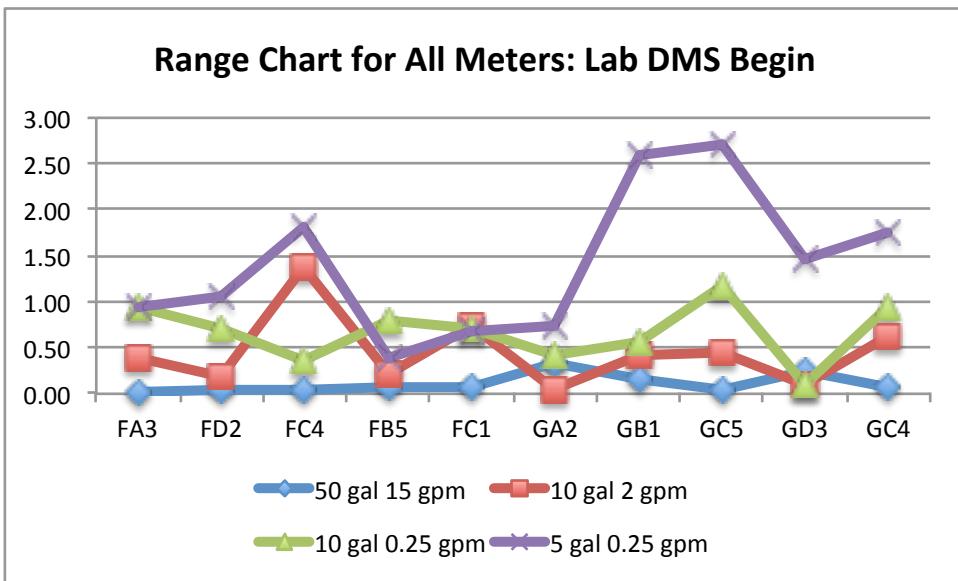
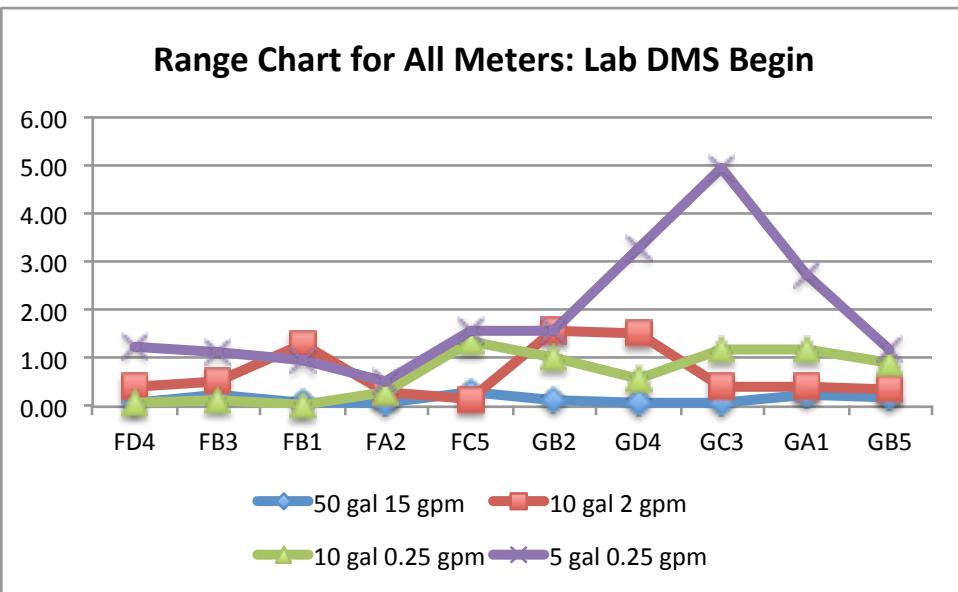
Range Chart for All Meters: Lab 94

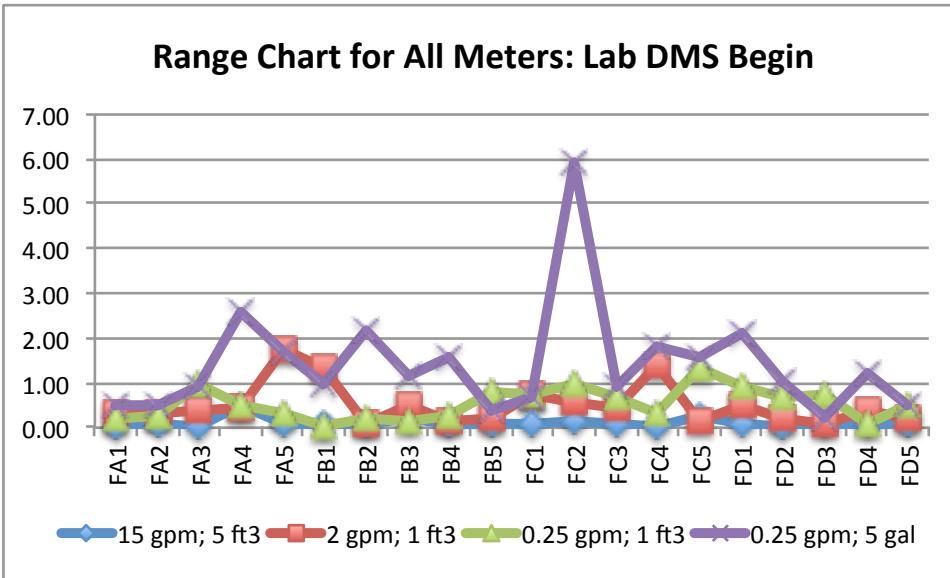


At the beginning of the survey, DMS tested all meters as the groups that were sent to the counties; however, the results were analyzed for the meters from each manufacturer. At the end of the survey, DMS tested the meters in the same groups that the counties tested the meters. The range values for the DMS results for each group of manufacturer's meters are shown on individual charts for the results at the beginning of the survey, that is, the range values for all meters from the same manufacturer are shown on individual charts. Next, the DMS results at the beginning of the survey for meters indicating in gallons (and then one chart for meters indicating in cubic feet) are shown together on a single chart. Similarly, the DMS results at the end of the survey for all groups of meters indicating in gallons are shown on a single chart and the range results for meters indicating in cubic feet are also shown on a single chart.

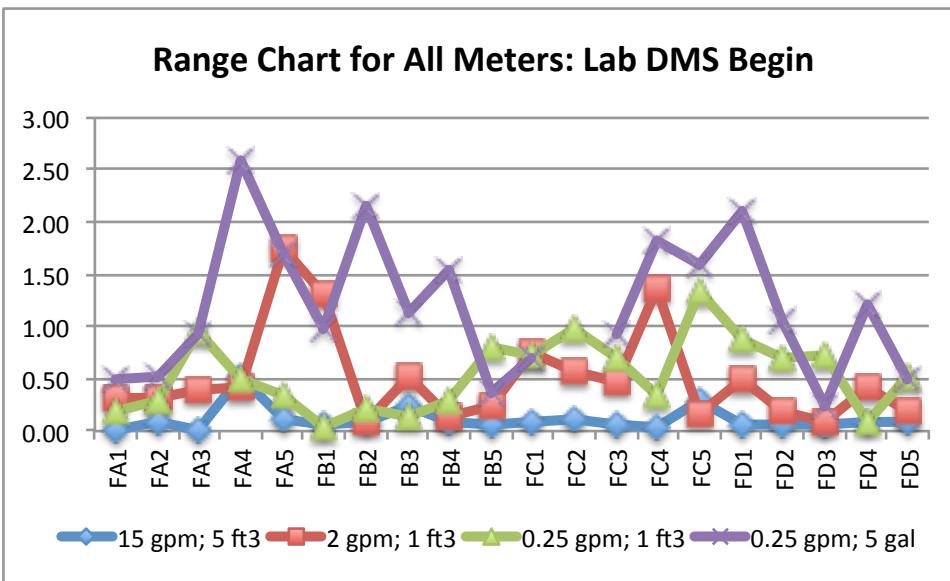
The manufacturers tested their own meters at the beginning and the end. Hence, The charts for the manufacturers' test results at the beginning of the survey can be compared to the DMS results at the beginning of the survey. However, because DMS tested the meters at the end of the survey in the same groups as the counties tested the meters, the DMS results at the end of the survey cannot be compared directly to the results for the manufacturers at the end of the survey. However, the DMS results at the end of the survey can be compared to the results for the California county laboratories by group if one wishes to do so.



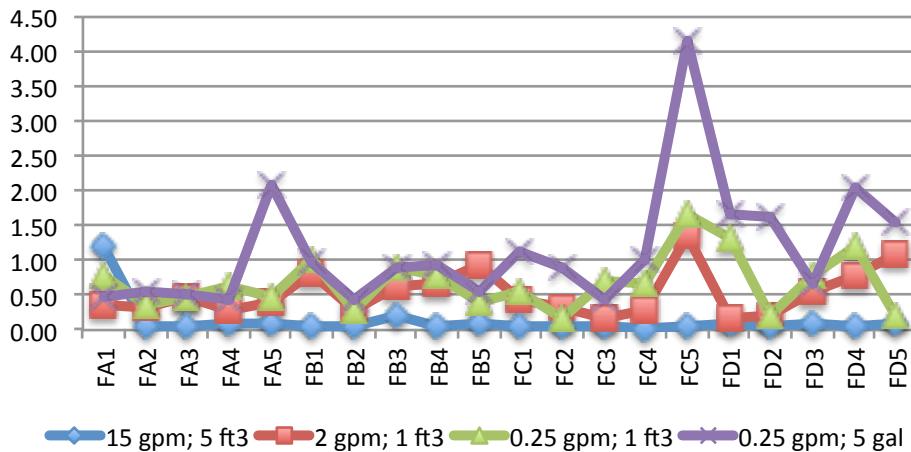




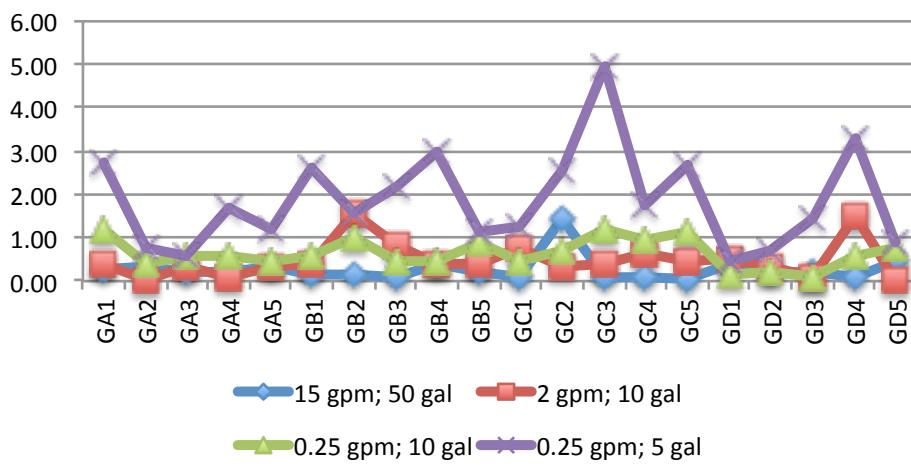
The chart below shows the DMS beginning values without the range value for FC2 so that the variations in the range values for the other meters are more easily visible.



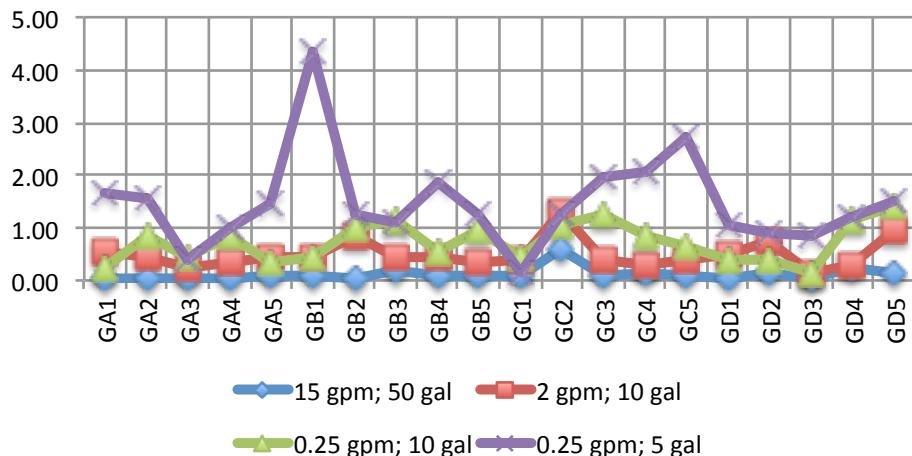
Range Chart for All Meters: Lab DMS End



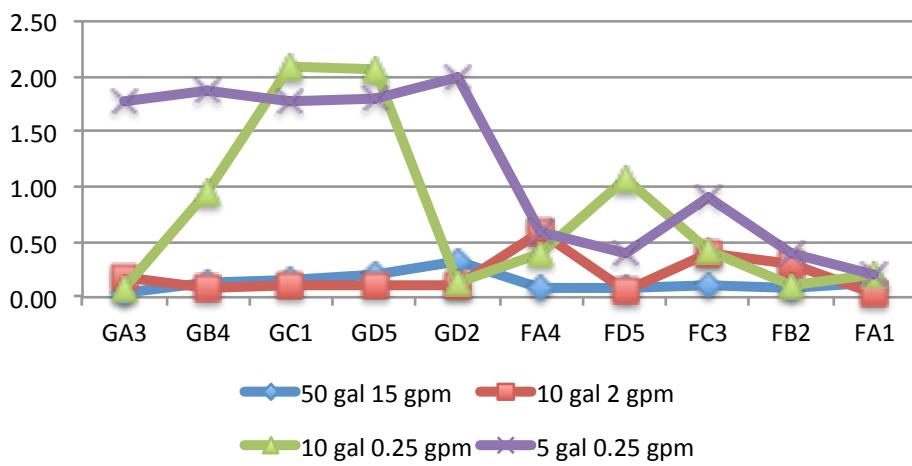
Range Chart for All Meters: Lab DMS Begin



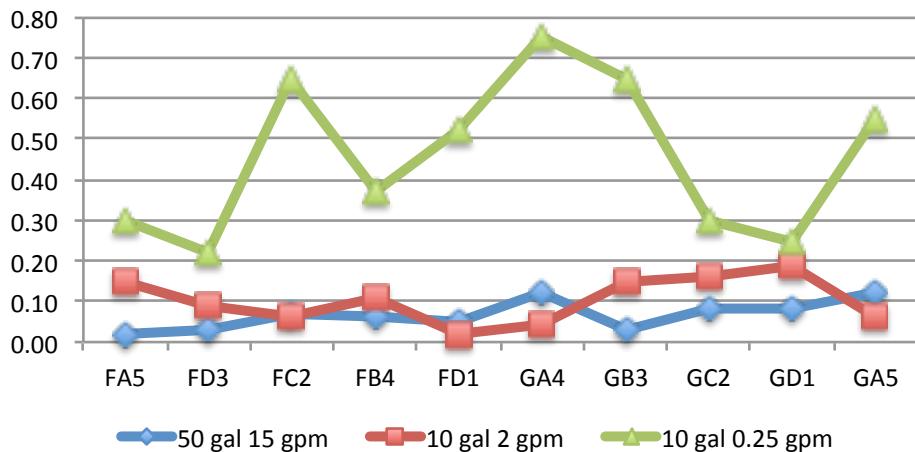
Range Chart for All Meters: Lab DMS End



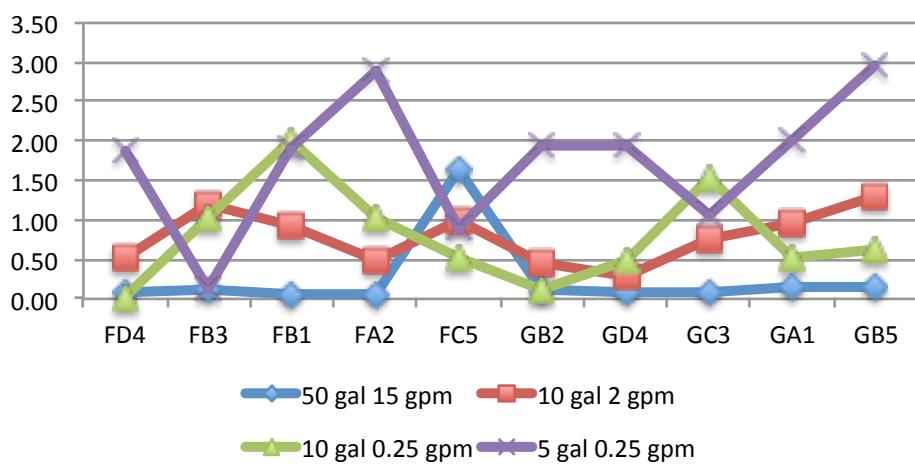
Range Chart for All Meters: Mfgr Lab Begin

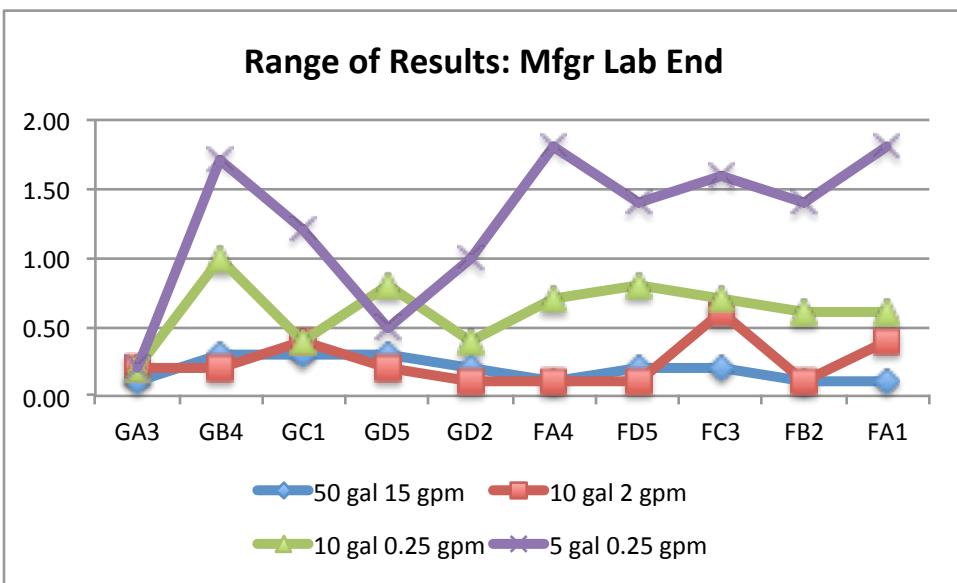
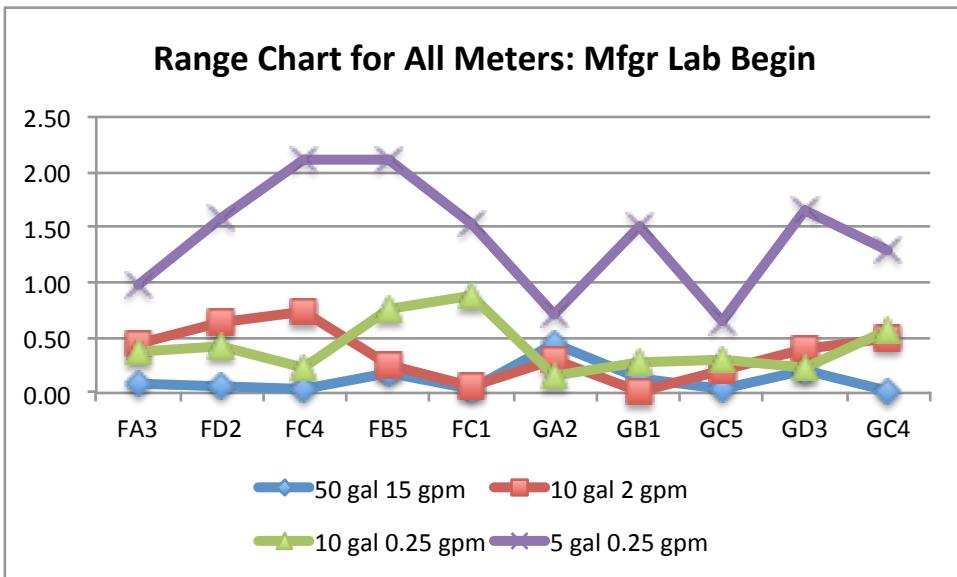


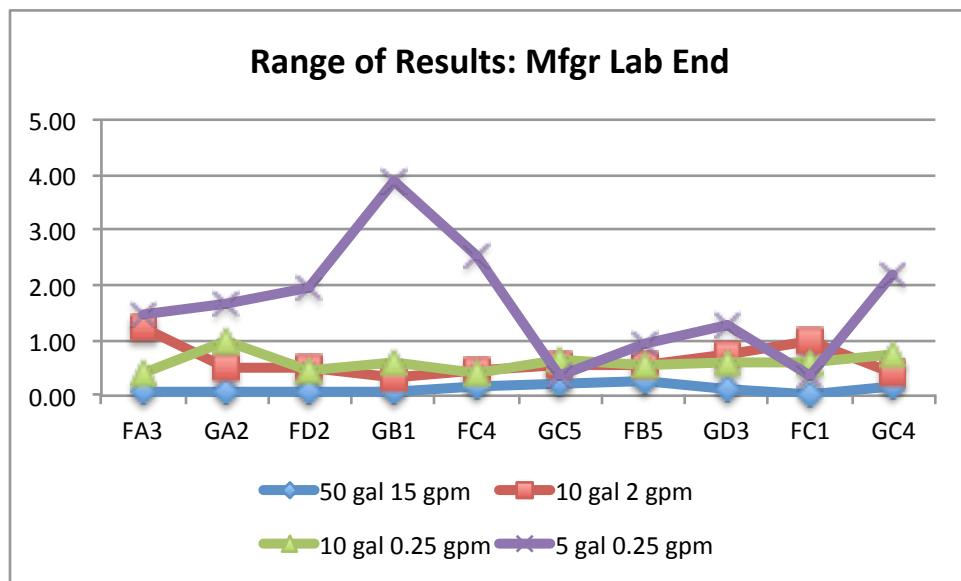
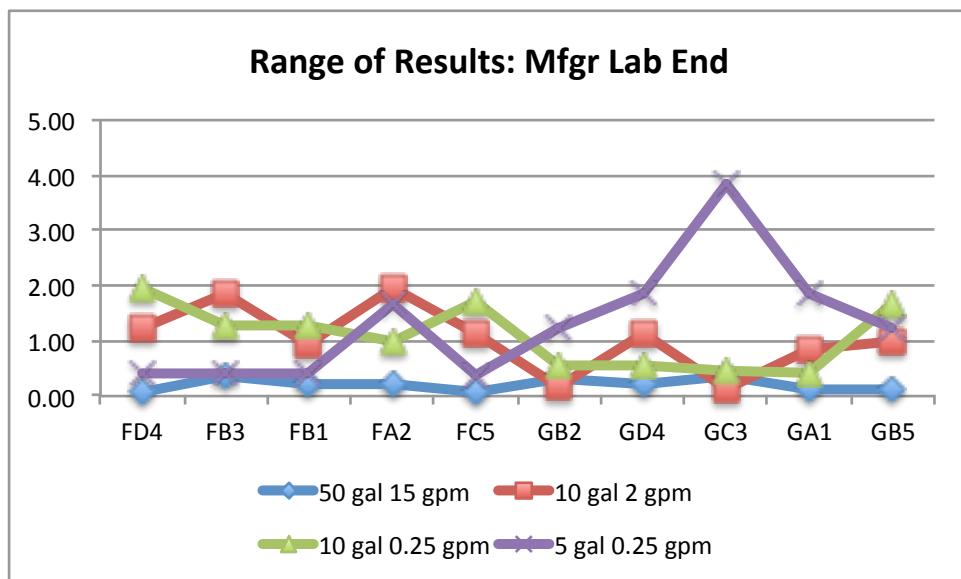
Range Chart for All Meters: Mfgr Lab Begin



Range Chart for All Meters: Mfgr Lab Begin







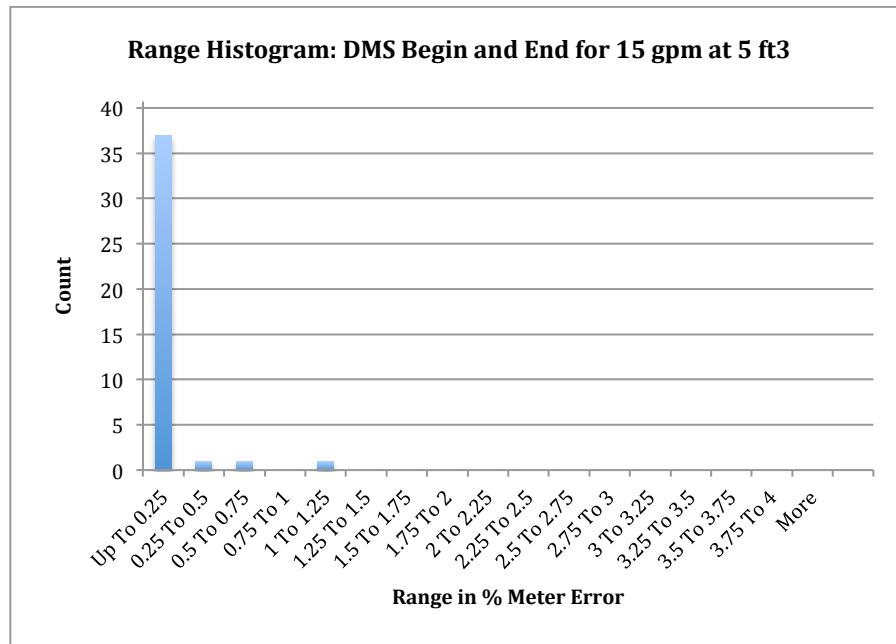
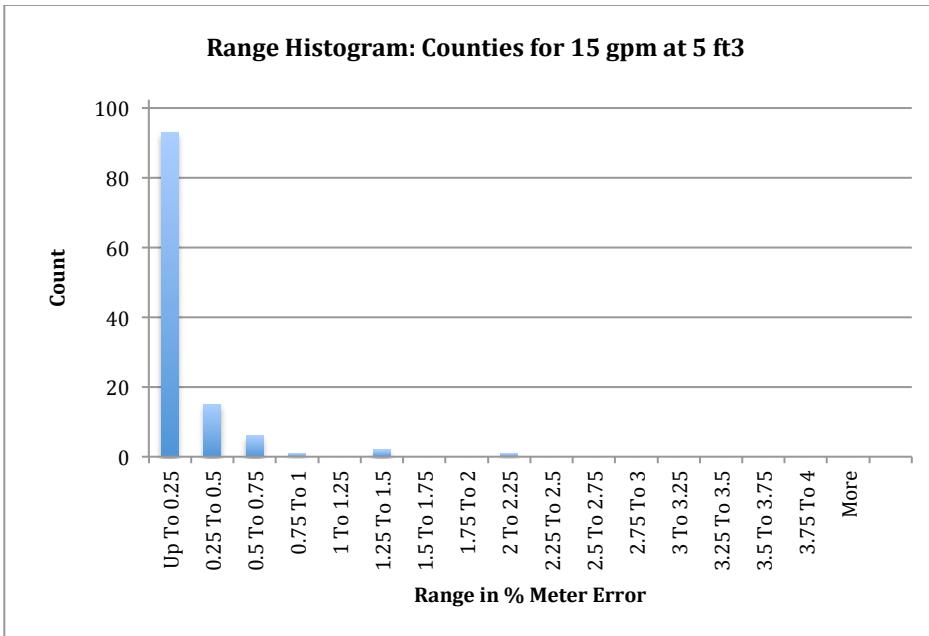
Histograms of the Range Results

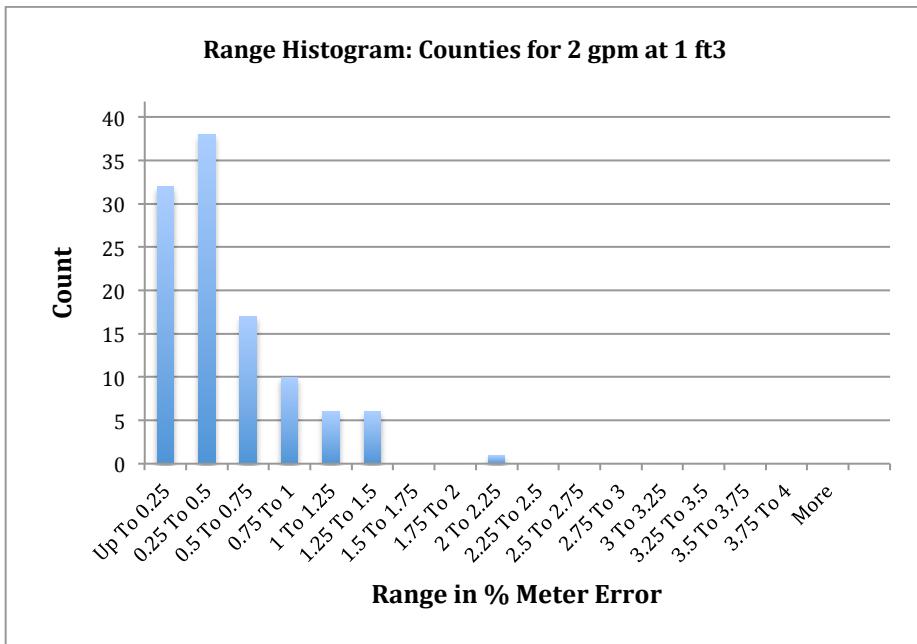
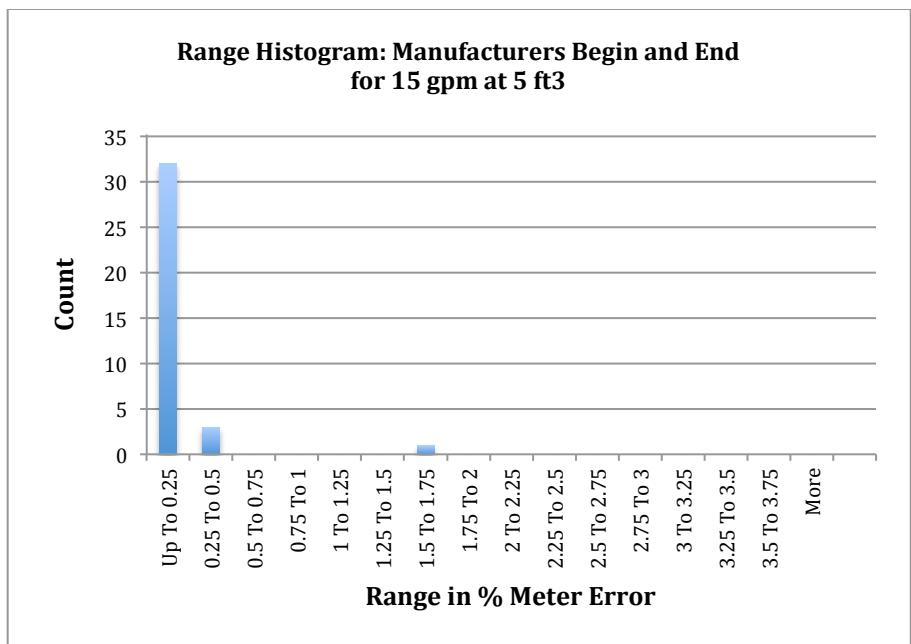
The charts of the range values for each laboratory for the different flow rates provide another illustration of the variations in the test results that are visible in the charts of the individual values of the test results for each meter. Basically, the variability of the percent meter error in the test results increases (1) as the flow rate decreases and (2) as the size of the test draft decreases.

An analysis of the range values for the different types of test laboratories (county, DMS and manufacturers) is necessary to interpret the results illustrated in the charts in the previous section. The test results for each flow rate and size of test draft are provided below. Histograms of the range values were generated for these flow rates and sizes of test drafts to allow one to compare the distribution of range values obtained by the different laboratories. The scale on the x-axes is the same for all of the histograms.

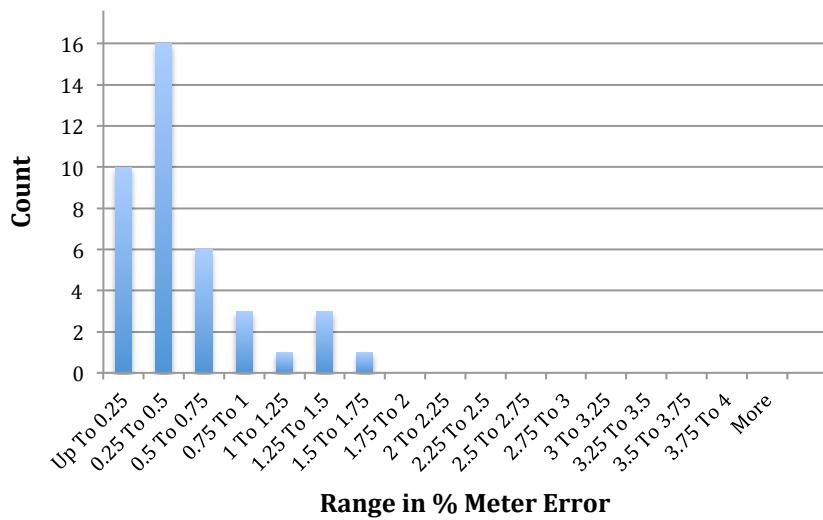
Next the mean and median values of the range values were calculated for the different types of test laboratories to allow a further comparison of the test results for the different laboratories. These values are shown in the table below.

Meters in ft ³	15 gpm at 5 ft ³		2 gpm at 1 ft ³		0.25 gpm at 1 ft ³			
	Mean	Median	Mean	Median	Mean	Median		
Counties	0.21	0.12	0.50	0.49	0.84	0.58		
DMS	0.12	0.07	0.52	0.41	0.61	0.59		
Mfgrs	0.16	0.06	0.57	0.48	0.69	0.58		
Meters in gallons	15 gpm 50 gal		2 gpm at 10 gal		0.25 gpm at 10 gal		0.25 gpm at 5 gal	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Counties	0.26	0.19	0.58	0.50	0.93	0.50	1.94	1.60
DMS	0.20	0.13	0.49	0.41	0.69	0.59	1.67	1.47
Mfgrs	0.16	0.14	0.38	0.20	0.65	0.55	1.40	1.50

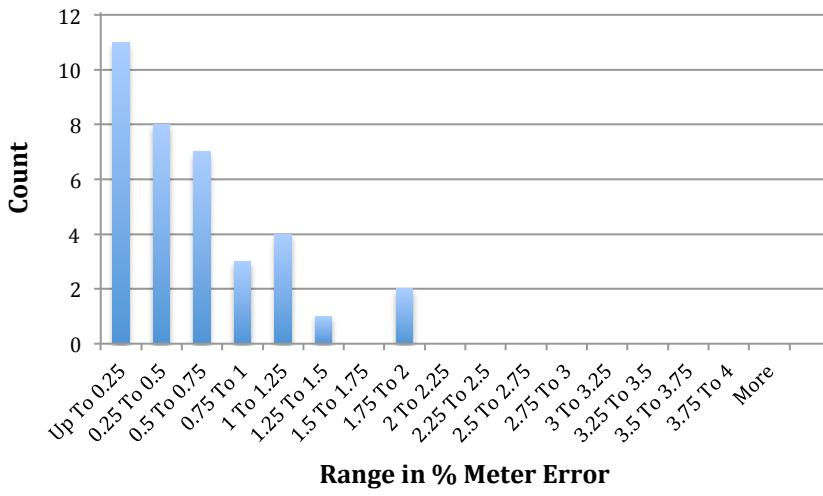


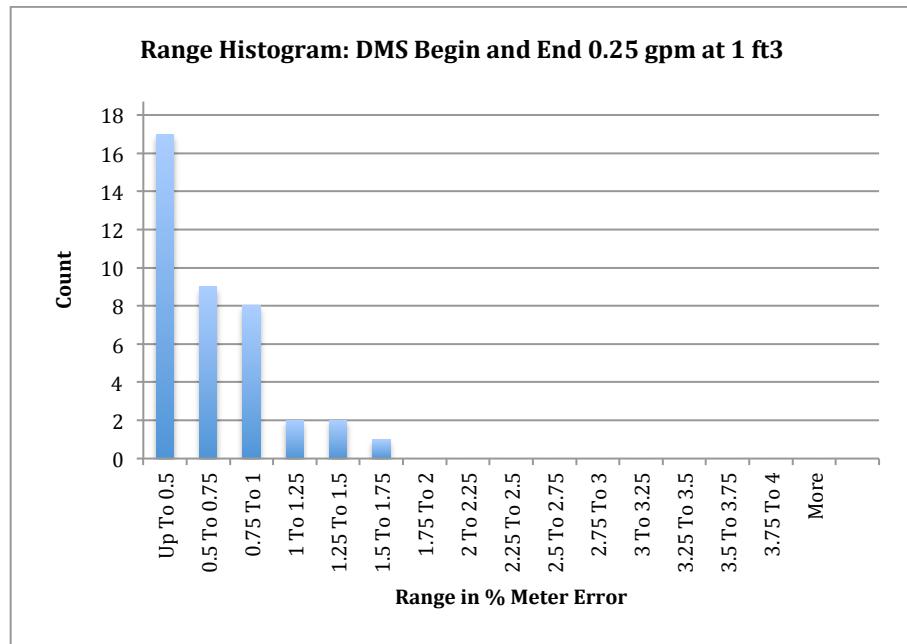
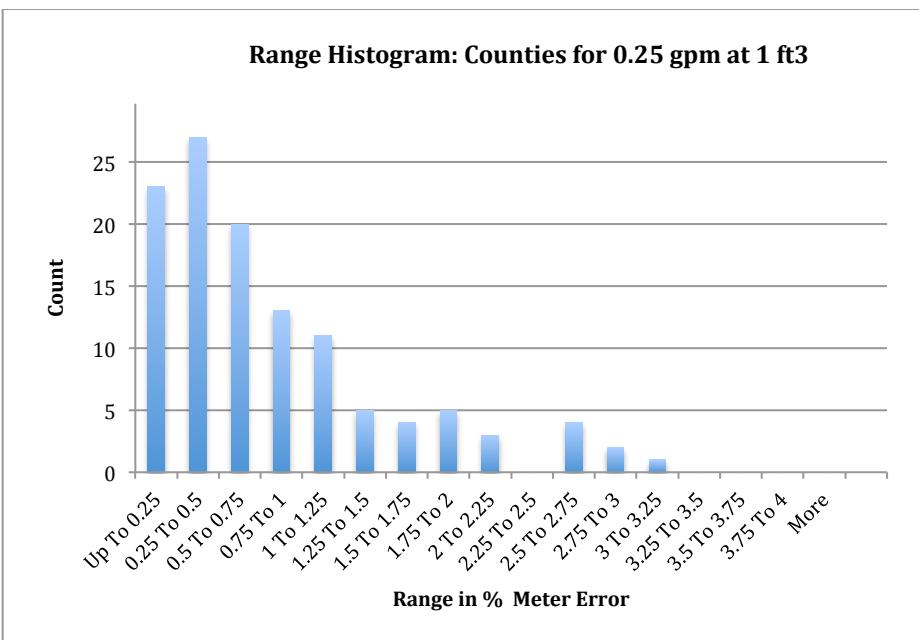


Range Histogram: DMS Begin and End for 2 gpm at 1 ft³

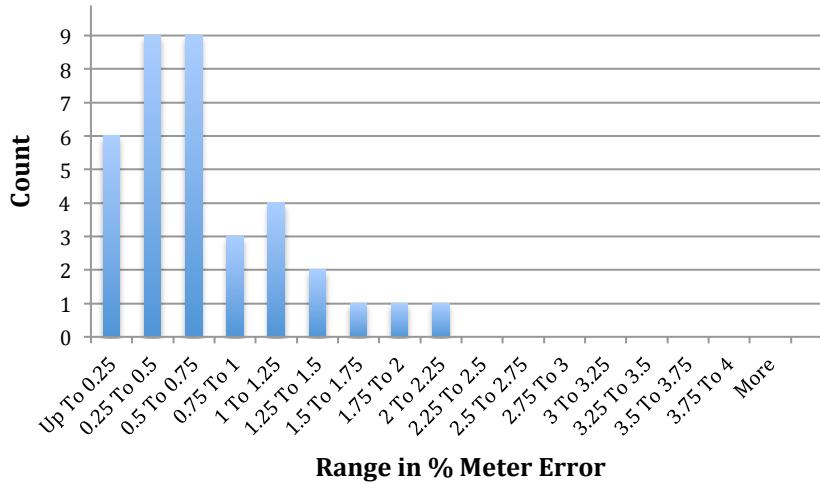


**Range Histogram: Manufacturers Begin and End
for 2 gpm at 1 ft³**

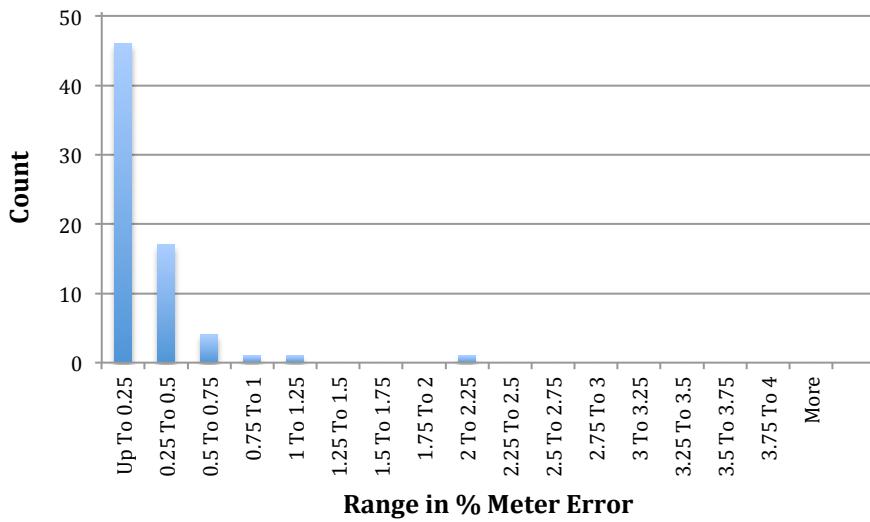




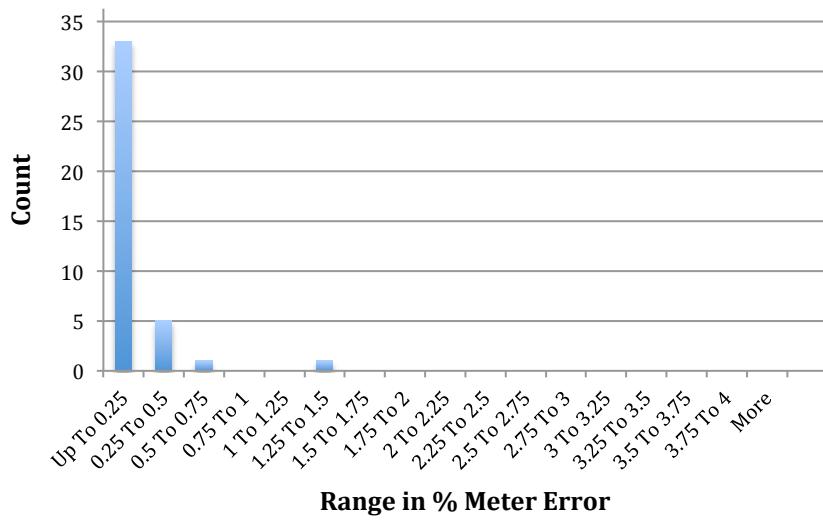
**Range Histogram: Manufacturers Begin and End
for 0.25 gpm at 1 ft³**



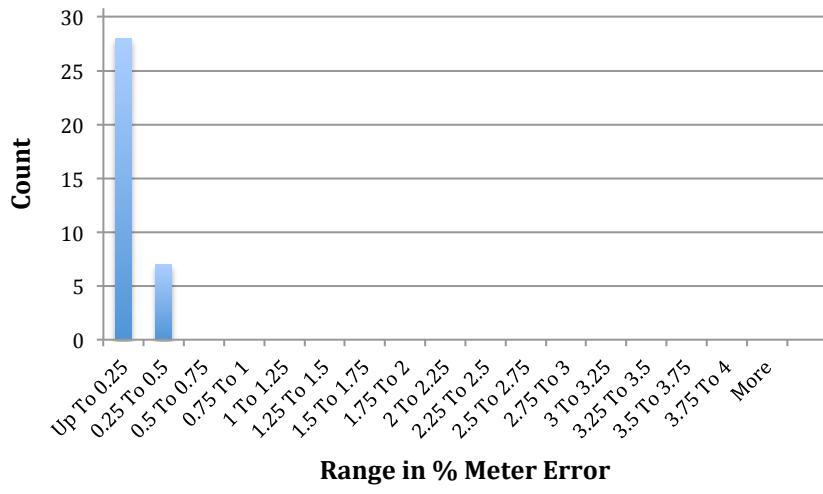
Range Histogram: Counties for 15 gpm at 100 gal

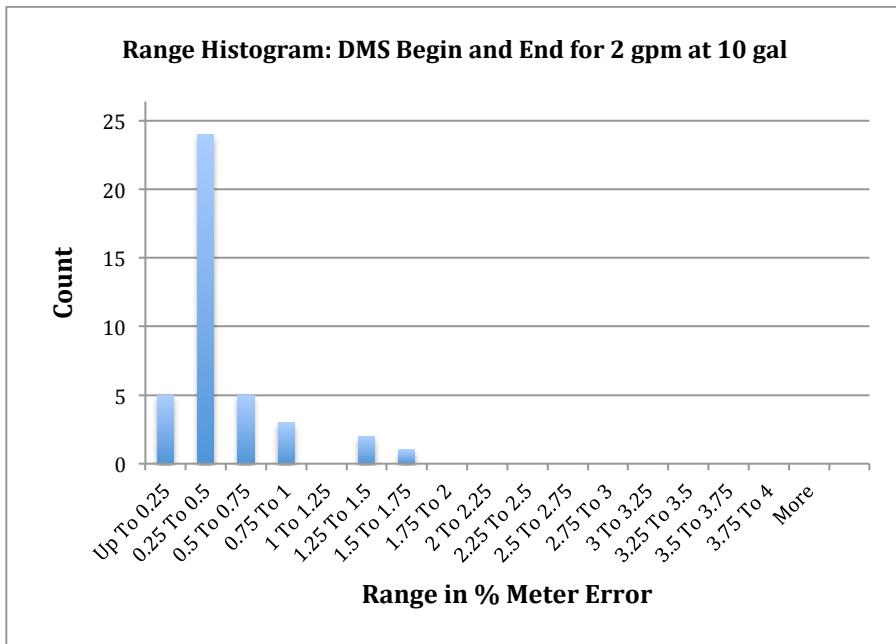
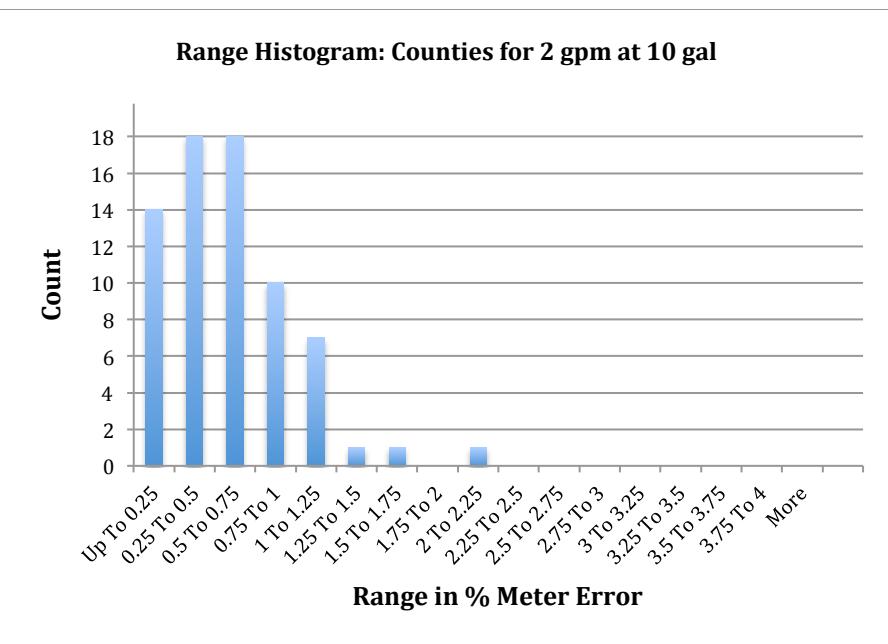


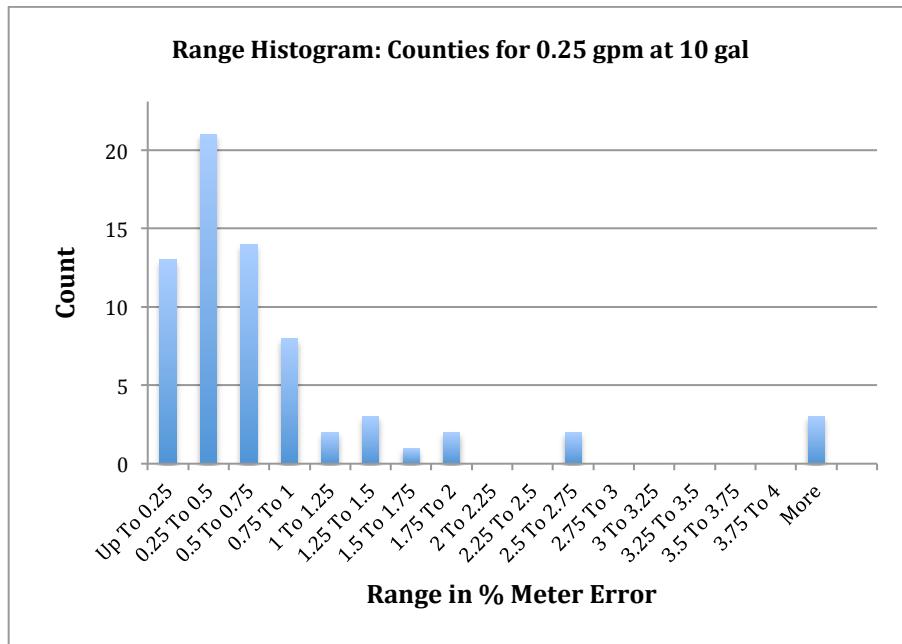
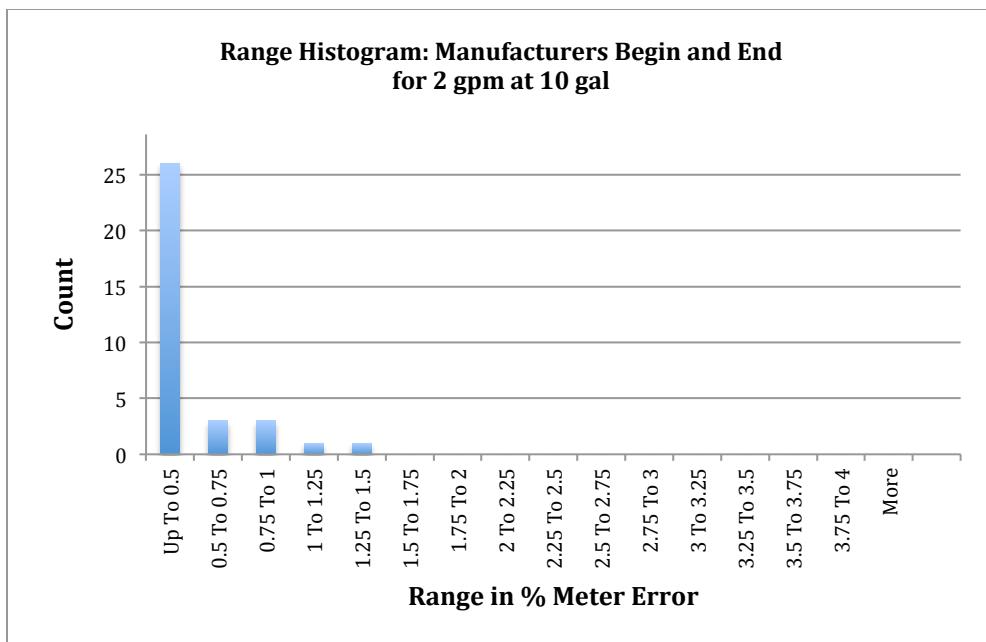
Range Histogram: DMS Begin and End for 15 gpm at 50 gal



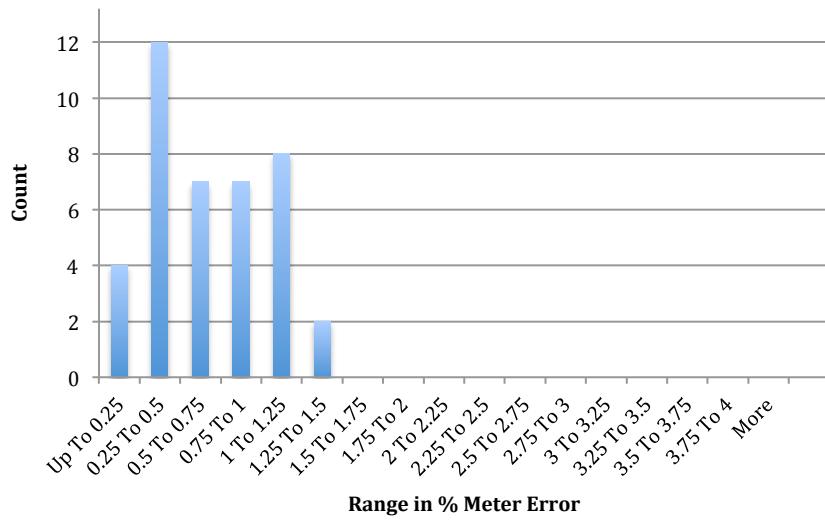
**Range Histogram: Manufacturers Begin and End
for 15 gpm at 50 gal**



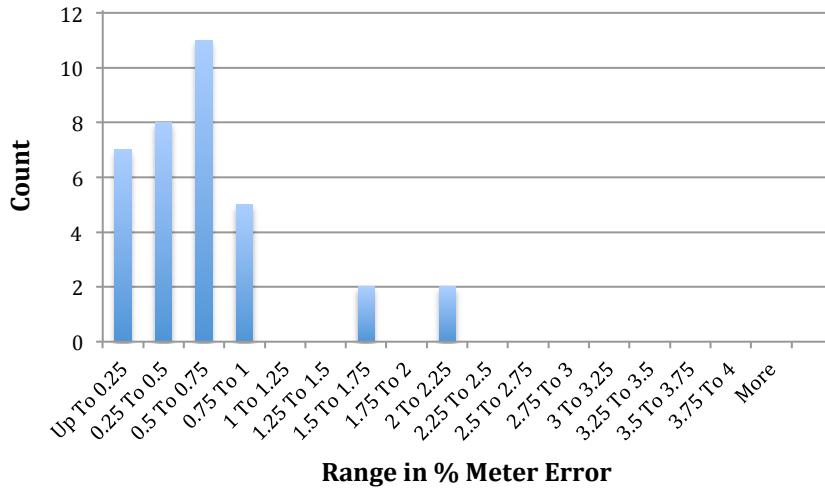


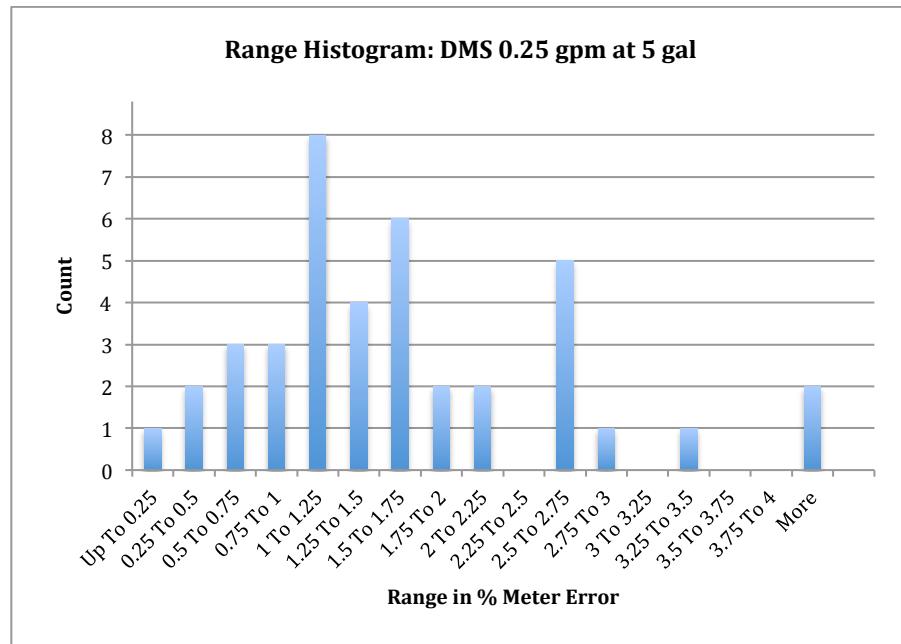
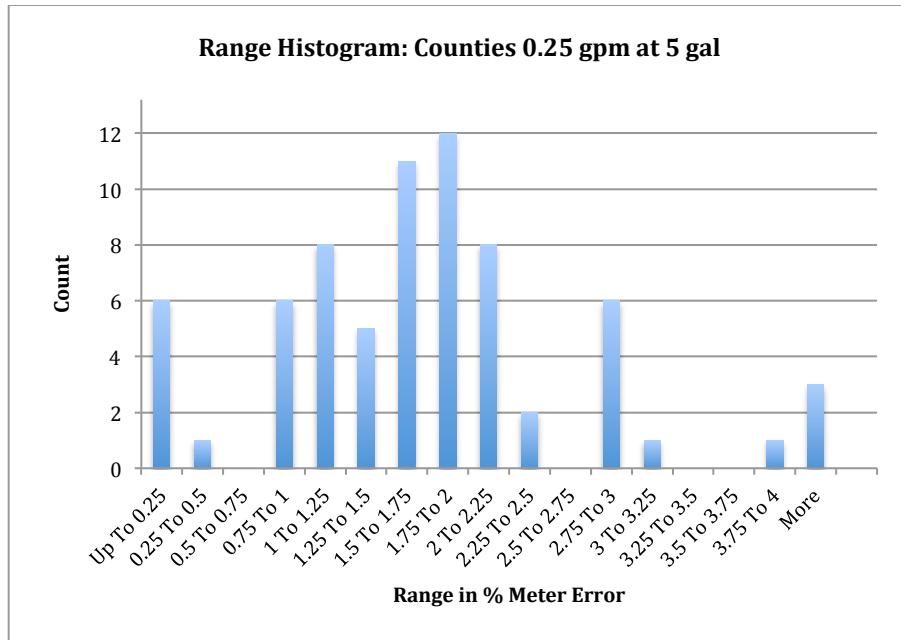


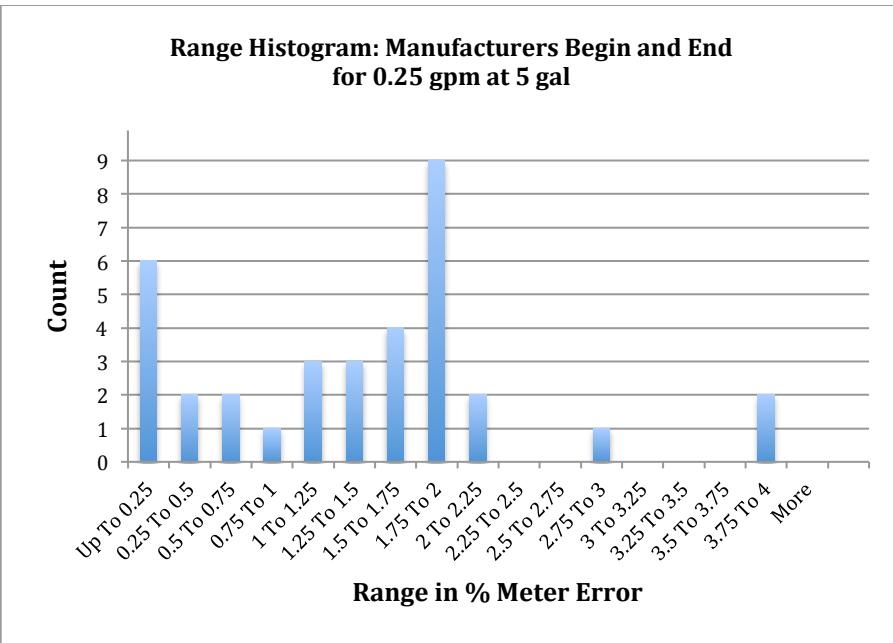
Range Histogram: DMS Begin and End for 0.25 gpm at 10 gal



**Range Histogram: Manufacturers Begin and End
for 0.25 gpm at 10 gal**



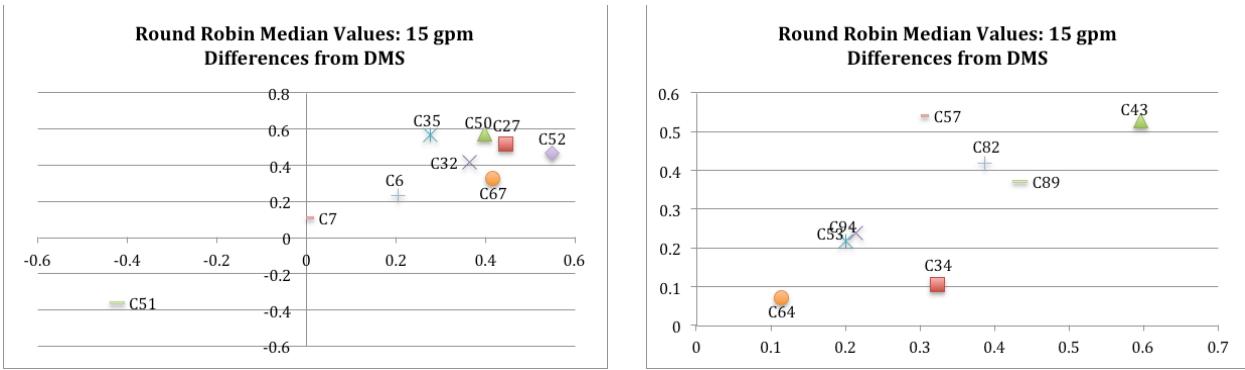




County Test Results

The test results for each individual county are shown as differences from the DMS results in a bar chart that shows each meter and all flow rates. If a county laboratory tested two groups of meters as part of the round-robin exercise, then two bar charts are shown. For the counties that participated in the round-robin exercise, the Youden plots for each flow rate are provided. However, it is helpful to look first at plots of the median values for those counties that participated in the round-robin exercise, because the locations of the median values provide some perspective when assessing all of the county results for each meter tested.

Below are the charts that show the median values for the differences of the counties that participated in the round-robin exercise, from the DMS values for each flow rate and each size of test draft. There are two graphs for each flow rate, except for the 0.25-gpm results for the 5-gal test draft, because it is easier to see the county codes. The county codes are preceded with a "C" to distinguish them from the numbers on the charts. The first pair of graphs is for the 15-gpm flow rate.

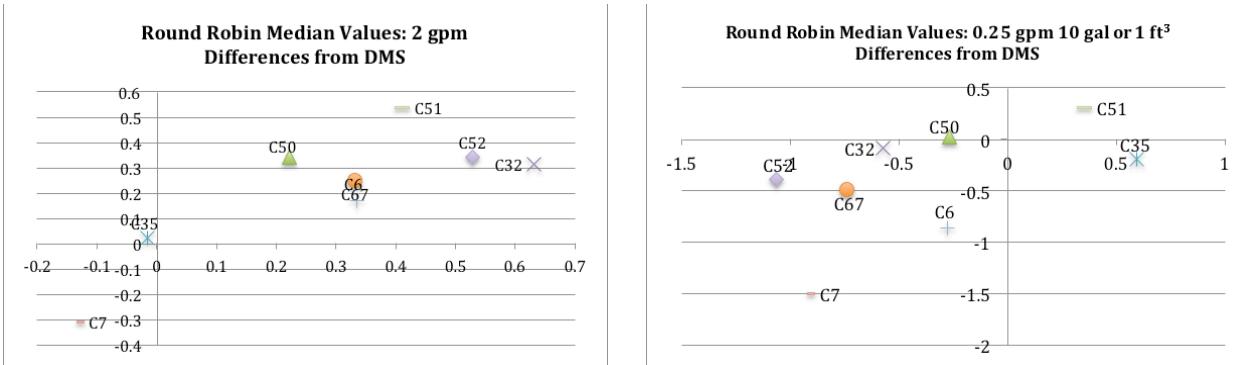


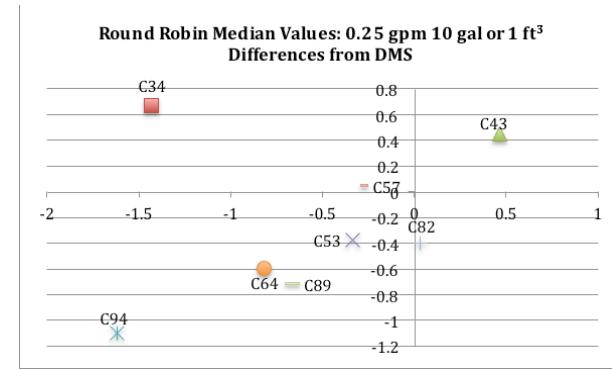
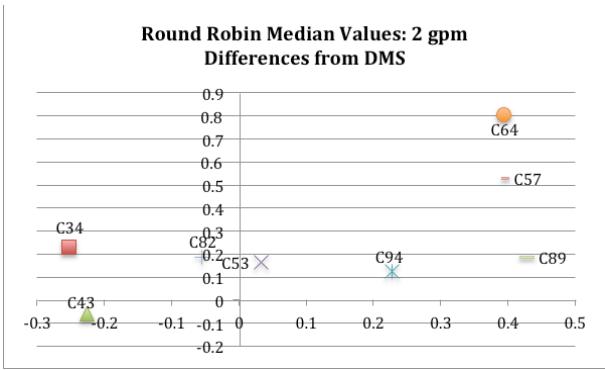
It is interesting to see that most of the median differences at 15 gpm for the county results compared to DMS indicate biases that are in the upper right quadrant. Many of the offsets are between 0.3% and 0.6% of the meter errors. The larger differences are significant compared to the meter tolerance of $\pm 1.5\%$. Since the test results for three of the four meter manufacturers agreed well with DMS at the flow rate of 15 gpm, these biases exist when compared to the manufacturers' results, as well. The fourth manufacturer had an offset from DMS of about +0.4%, so the results from the counties would generally agree well for the fourth manufacturer at this flow rate.

County 51 is the exception to the pattern at 15 gpm, because the median values for the differences from DMS are offset by about -0.4%. The negative bias at 15 gpm resulted in more meters found outside of tolerance at 15 gpm than any of the other counties. An odd aspect is that this county shows one of the largest positive offsets for test results at 2 and 0.25 gpm. The possible causes of these offsets are not obvious. Visually, County 51 has an excellent test facility in a relatively controlled temperature environment, has a Ford water meter test bench, uses city water for all tests, and the test official demonstrated great care in conducting the tests and recording the results. It is recommended that these offsets be explored in an effort to identify causes.

Counties C7 and C64 show the best agreement with DMS at 15 gpm.

Below are the median differences from DMS for the counties at 2 and 0.25 gpm for the 10-gal (1 ft^3) test draft.





At the flow rate of 2 gpm, there appears to be a positive bias to the county test results, but it is not as consistent as at 15 gpm. At 0.25 gpm for the 10-gal test draft, the counties tend to generate more negative test results than DMS. The same is true for the county results at the flow rate of 0.25 gpm at the 5-gal test draft shown to the right.

The table below identifies the meters that failed either the accuracy and repeatability tests by the various test labs. The table may be helpful when reviewing the test results for all test labs for each meter. The values following the meter codes are the percent meter error or the range of the meter errors.

